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LOW FLOW, OPEN WATER
TRACER DYE STUDIES
ON THE
NORTH SASKATCHEWAN RIVER,
EDMONTON TO SASKATCHEWAN BORDER

1991-15

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1991-15

by

G. Van Der Vinne

Environmental Research and Engineering Department
Alberta Research Council

for

Alberta Environment

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ABSTRACT

Two tracer dye tests were carried out on the North Saskatchewan River to define the hydraulic and mixing characteristics of the river reach between Edmonton and the Saskatchewan border for low flow, open water conditions. Subreach average discharges ranged from 108 m^3/s to 168 m^3/s. The mean water velocities calculated from the travel time of the peak dye concentration was 0.64 m/s in the reach between Edmonton and Shandro and 0.54 m/s in the reach between Shandro and the Saskatchewan border. Manning's roughnesses varied between 0.025 to 0.053. These roughnesses can be used to extrapolate velocities at other discharges provided that the hydraulic characteristics do not change significantly.

Both Linear and Fickian dispersion occurred in the test reaches. The Linear dispersion parameter was found to be 0.00416 for the Edmonton injection and 0.00353 for the Shandro injection. These values are lower than the values measured in the same reaches the previous winter under an ice cover. The Fickian dispersion coefficient was found to be 266 m^2/s for the upper test reach and 168 m^2/s for the lower test reach. These values are consistent with values reported in the literature for channels of similar width and roughness. The location of the transition between Linear and Fickian dispersion was found to depend on the position and number of injection points in the cross-section.

Both the Linear and Fickian dispersion models predicted much more symmetrical distributions than were actually observed. The models accurately predict dispersion in uniform channels but the variations in geometry in natural rivers causes additional mixing which the models do not predict.

ACKNOWLEDGMENTS

The work reported herein resulted from a joint venture undertaken by the Environmental Protection Service of Alberta Environment and the Surface Water Engineering Group of the Environmental Research and Engineering Department, Alberta Research Council.

Numerous individuals contributed to and provided support for this project. J. Thompson, B. Trevor, P. Mostert and M. Huemmert of the Alberta Research Council performed the field work with support from two casual employees. Both the Water Survey of Canada and the Water Survey Section of Alberta Environment provided discharge estimates. Alberta Environment also provided a fluorometer for use in this study.

The results achieved were very much a function of the skills developed over many years of involvement with the ongoing Alberta Cooperative Program in Transportation and Surface Water Engineering, participants of which are the Alberta Research Council, Alberta Transportation and Utilities, Alberta Environment, and the Department of Civil Engineering, University of Alberta.

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1.0 INTRODUCTION

1.1 Background

Increased awareness of environmental issues has prompted a reevaluation of the impacts of effluent discharges on the water quality of many Alberta rivers. Water quality modeling techniques are now being used to reassess the impacts of effluents from existing sources as well as to assess the potential impacts of effluents from new sources. These models provide a better understanding of the effects of effluents on river water quality; however, the models can only be used confidently if the hydraulic and mixing characteristics of the rivers are known.

The most critical conditions for water quality in rivers in northern Alberta usually occur during the low flow, ice covered conditions during the winter period; but, problems may also occur during low flow, open water conditions in late summer or early autumn. These low flows reduce the effluent assimilation capacity of the rivers. Unfortunately, there is a distinct lack of information on the hydraulic and mixing characteristics for these low flow conditions.

Effluent discharges from the Edmonton area, such as from the sewage treatment plant, are being reassessed using the water quality models. One of the first steps in this assessment process is to determine the hydraulic and mixing characteristics of the river system downstream from the effluent outfall during the critical low flow periods. To this end, the Alberta Research Council was requested by Alberta Environment to conduct tracer dye studies on the North Saskatchewan River between Edmonton and the Saskatchewan border in March and October of 1990 to measure travel times and to determine the longitudinal dispersion characteristics in this river reach during low flows. The results of the tracer dye studies done in March are available in Van Der Vinne (1991). This report deals with the results of the October tests.

1.2 Objectives

This report addresses the objectives of the tracer dye studies conducted on the North Saskatchewan River in October, 1990. These objectives are to:

1. determine the travel times relative to the hydraulic characteristics for low flow open water conditions;

2. extrapolate travel times over a range of possible low flow discharges; and

2. evaluate the longitudinal dispersion characteristics relative to the hydraulic characteristics.

2.0 FIELD INVESTIGATIONS

2.1 Study Reaches

The 336.3 km length of the North Saskatchewan River between Edmonton and the Saskatchewan border was divided into two reaches for which separate dye tests were carried out. The length of the upstream reach was 197.1 km while the length of the downstream reach was 189.6 km. The reaches were overlapped for 50.4 km between Shandro and Duvernay to compare the velocity measurements at the beginning and end of a test. These reaches were also chosen so that each dye test would be approximately the same duration.

Figure 1a-b illustrates the entire length of the river between Edmonton and the Saskatchewan border and indicates the pertinent river distances (from the mouth), the two study reaches, locations where dye was injected, and the sample sites. Table 1 summarizes some of this information. The dye was always injected at the upstream end of each reach and concentrations were measured at five or six locations downstream. The subreaches varied in length from 20 km to 50 km depending on the availability of access. Dye injections proceeded from downstream to upstream to eliminate background interference from residual dye remaining from upstream tests.

2.2 Methodology

2.2.1 Injection

For each dye test, a predetermined volume of 20% Rhodamine WT dye was mixed with an equal volume of methyl alcohol. The methyl alcohol was used to adjust the specific gravity of the dye mixture to that of water. Multiple injection points in the cross-section were used at both injection sites to reduce the initial concentrations and reduce the distance needed to complete the transverse mixing process. At injection, the flow width was determined and the injection points spaced evenly across the channel. The number of injection points at each of the sites

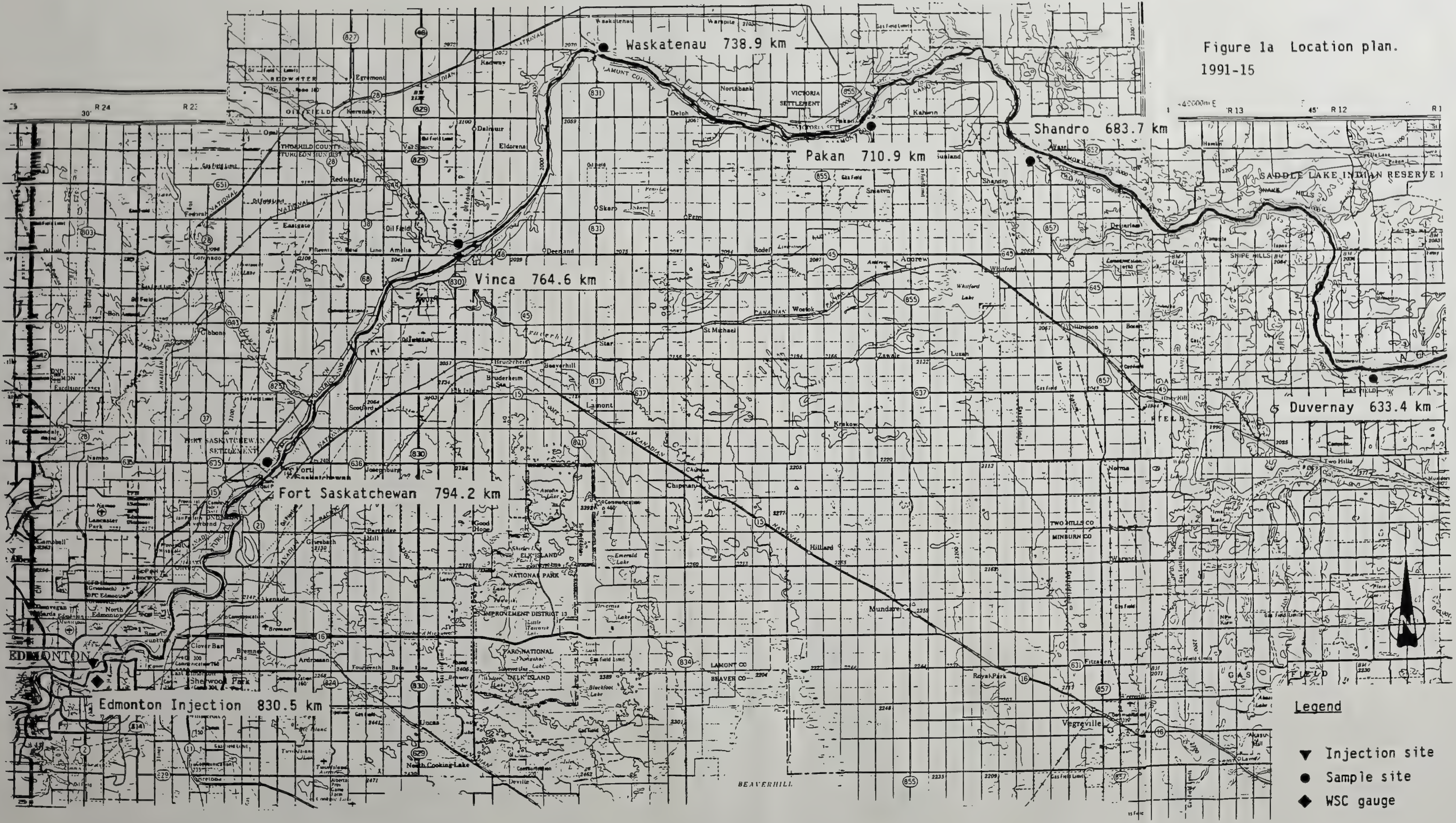

Figure 1a Location plan.
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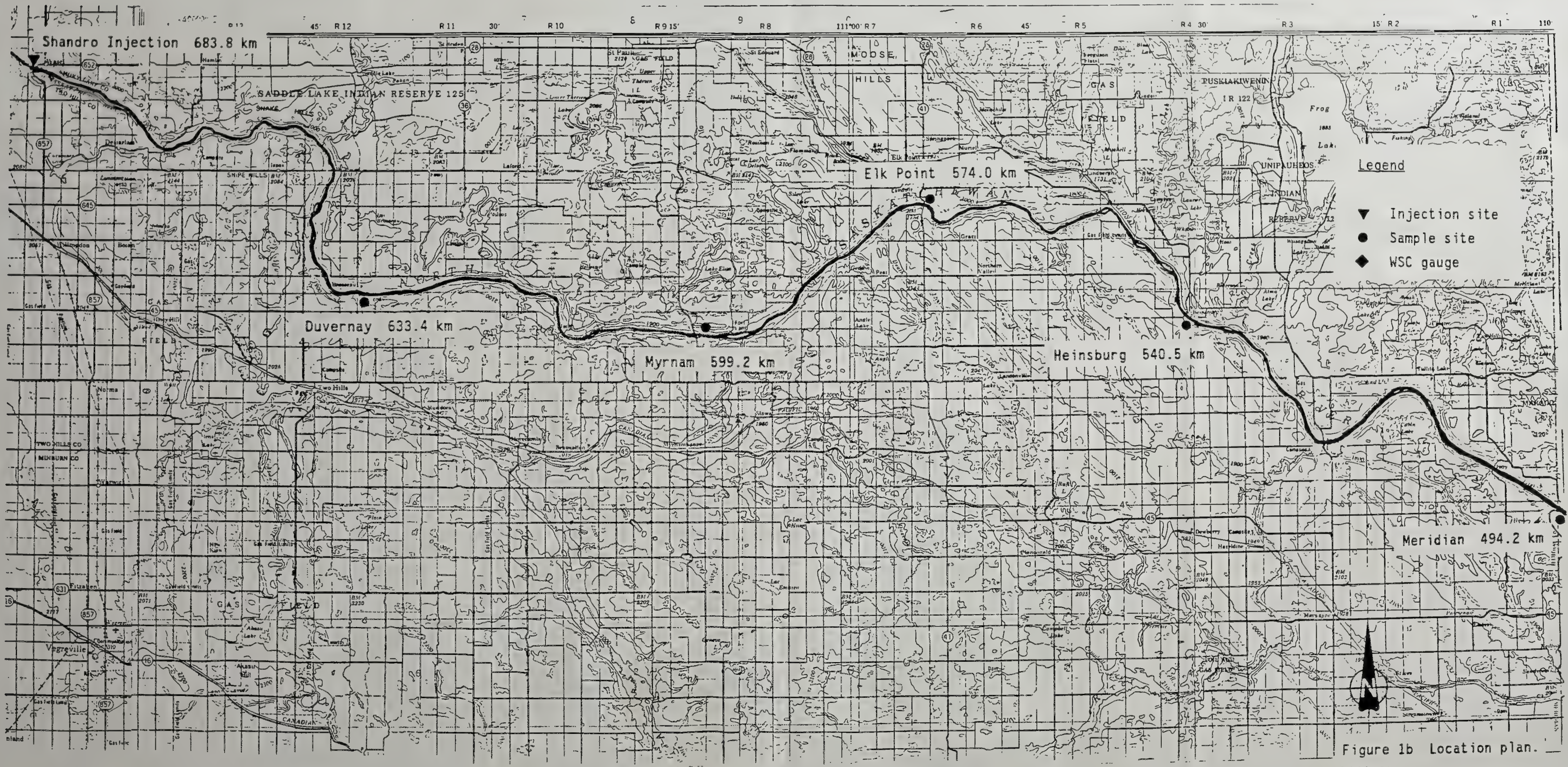

Figure 1b Location plan.

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Table 1 Summary of field program.

Reach	Length (km)	Date (1990)	Number of Sample Sites	Duration of Test (hrs)	Dye Volume (liters)
Shandro - Meridian	189.6	Oct.08-Oct.13	5	117	16.8
Edmonton - Duvernay	197.1	Oct.16-Oct.20	6	104	16.8

were the same as for the previous winter tests.

Two injection points were used for the Shandro injection, approximately one-third of the width from each bank. The injections were done from a boat, first one-half of the dye on the right side and then the other half on the left side. The left side injection was sightly downstream of the right side, to compensate for the slight time difference between the two injections.

The Edmonton injection was done from the Cloverdale pedestrian bridge just downstream of the Low Level bridge. The injection was done by using ropes to lower three buckets, each with one-third of the dye, to points just above the water surface. Another set of ropes attached to the bottoms of the buckets were then used to invert the buckets, pouring the dye into the river. The buckets were then immediately dropped into the river to wash away any remaining dye. This procedure produces a surface injection; however, the momentum of the dye causes it to mix well with the water rather than float on the surface.

2.2.2 Sampling

The sampling sites were established at locations where access was available. Following injection at the upstream end of the river reach being characterized, two crews of three persons followed the dye cloud

downstream, each of the crews sampling at alternating sites. At each site, floats were set in the river to mark the sample locations. The water level was referenced to benchmarks so that they could be compared to cross-sections provided by Alberta Environment.

The dye cloud was sampled over three holes across the channel. The centerline sampling location was established in the main part of the flow and two secondary sampling holes were established midway between the centerline sampling hole and both the left and right banks. Sufficient samples were taken at each of the sampling sites to completely characterize the dye cloud. Two or more samples were taken to establish background fluorescence levels and at least 20 samples were taken over the duration of the dye cloud. The interval between samples varied between 5 minutes and 2 hours, depending on the duration of the dye cloud. The secondary sample sites were established to assess the extent of lateral mixing and to improve the estimates of the total volume of dye passing the sampling site.

As mentioned earlier, the entire dye cloud was measured as completely as possible. Special care was taken to define the time of first rise and the time of peak. Generally, the frequency of sampling was increased during those two periods. On the falling limb of the concentration curve, sampling was continued until it was judged that the fluorescence was reduced to 20% of the peak and that the tail of the curve could be confidently extrapolated. In some cases, however, the tails of the dye cloud were cut short in order to give sufficient time to go to the next sampling site.

As soon as the samples were collected, they were transported to the mobile laboratory which each crew had at its disposal. After the temperatures of the samples were measured, the samples were immediately run through the Turner Designs Model 10 fluorometer and the results recorded. Where the scales on the fluorometer overlapped, readings were taken on both scales to ensure consistency over the range of the two scales of the fluorometer.

2.2.3 Calibration and Data Reduction

Two fluorometers were used during the field study - the ARC Turner Designs Model 10 field unit and the Alberta Environment Turner Designs Model 10 rack mounted unit. Each was kept with the same crew for the duration of the entire campaign. Prior to the field work, a set of standards was prepared and both instruments were calibrated at 20°C for the set of standards over a number of scales. A simple least squares linear relationship was established for each scale and the fluorescent values recorded in the field were transformed into true fluorescent values, and then adjusted to compensate for temperature. The data was then plotted and the pertinent characteristics computed.

2.3 Discharge Measurements

Discharge measurements necessary to characterize the hydraulic conditions of each of the reaches were made by the Water Survey Section of Alberta Environment and the Water Survey of Canada. Three discharge measurements were generally made in each test reach. The first measurement was made as close as possible to the time and location of the injection, the second measurement was made at a sample site near the midpoint of the reach, and the third measurement was made at the end of the reach near the last sample site. Measurements were also made on major tributaries at the appropriate times.

Discharges at each of the sample sites had diurnal fluctuations due to the operation of a hydroelectric plant upstream of Edmonton. Water levels at the sample sites were monitored every two hours so that the fluctuations could be matched with those from Water Survey of Canada water level gauges at Edmonton and at Deer Creek in Saskatchewan. Fluctuations in discharge were estimated from rating curves for these sites. Discharges used in the following analysis were the estimated average discharges for the periods of interest. Table 2 summarizes the adopted discharges used in the travel time analysis.

Table 2 Summary of adopted reach-averaged discharges.

Reach	Date	Discharge (m^3/s)
Edmonton Injection		
Edmonton - Ft. Saskatchewan	Oct. 16	129
Ft. Saskatchewan - Vinca	Oct. 16 - 17	132
Vinca - Waskatenau	Oct. 17	142
Waskatenau - Pakan	Oct. 17 - 18	161
Pakan - Shandro	Oct. 18	168
Shandro - Duvernay	Oct. 18 - 19	156
Shandro Injection		
Shandro - Duvernay	Oct. 08 - 09	152
Duvernay - Myrnam	Oct. 09 - 10	127
Myrnam - Elk Point	Oct. 10	108
Elk Point - Heinsburg	Oct. 10 - 11	112
Heinsburg - Meridian	Oct. 11 - 12	130

3.0 TRAVEL TIME ANALYSIS

3.1 Channel Hydraulics

The North Saskatchewan River between Edmonton and Meridian bridge has an irregular meander pattern with point bars, side bars, mid-channel bars and occasional islands. Hydroelectric power production upstream of Edmonton produces a diurnal fluctuation of about 30% around the mean discharge. Mean flows also tend to be high because the river is regulated. Hydraulic characteristics were determined from cross-sections surveyed every five to ten kilometers over the whole reach. These surveys were performed in June and July of 1990 by crews from Alberta Environment.

The average times of travel of the leading edge, the peak, the centroid, and the trailing edge of the dye cloud for each subreach are listed in table 3. As well, the cumulative travel times for each test are plotted against distance from injection in figures 2a-b. The slope of the lines in these figures are inversely proportional to the velocities. For example, in both cases the velocity of the peak is about 5% faster than the velocity of the centroid.

This difference in velocity between the peak and the centroid of the time-concentration curves raises the question of which quantity represents the average velocity of the water. Obviously, the centroid is the measure of the average velocity of the dye mass but this velocity only corresponds to the average water velocity in a uniform laboratory channel where all areas of the channel contribute to the flow. In natural streams, however, the cross-section variability causes zones of stagnant or very slow moving water. These zones contribute little if anything to the discharge therefore they should not be included in the determination of average velocity. The travel time of the centroid of the dye cloud is affected by these stagnant zones especially if they produce long drawn-out receding limbs. Alternatively, the cross-section average velocity of the peak concentration incorporates the cross-sectional variations in velocity but does not include the effects

Table 3 Subreach average travel times.

Subreach	Length	Travel Times			
		Leading Edge	Peak	Centroid	Trailing Edge
	(km)	(hrs)	(hrs)	(hrs)	(hrs)
Edmonton -Fort Saskatchewan	36.3	15.79	16.50	17.44	21.30
Fort Saskatchewan -Vinca	29.6	11.70	11.83	13.46	17.51
Vinca -Waskatenau	25.7	9.90	10.84	11.50	12.60
Waskatenau -Pakan	28.0	10.30	10.83	11.41	15.33
Pakan -Shandro	27.2	11.10	13.50	12.70	14.34
Shandro -Duvernay	50.3	21.32	25.00	23.86	26.58
Shandro -Duvernay	50.4	21.45	22.50	23.49	28.31
Duvernay -Myrnam	34.2	15.44	17.50	19.13	23.04
Myrnam -Elk Point	25.2	13.63	15.00	15.23	17.73
Elk Point -Heinsburg	33.5	17.10	20.00	20.27	25.86
Heinsburg -Meridian	46.3	24.58	26.50	26.12	25.69

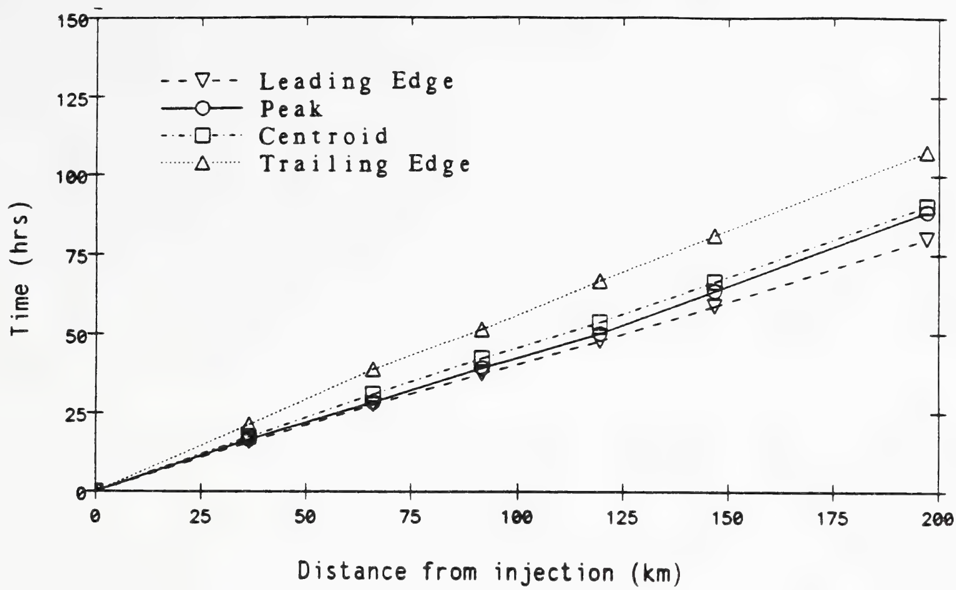


Figure 2a Growth of travel times with distance from injection, Edmonton to Duvernay.

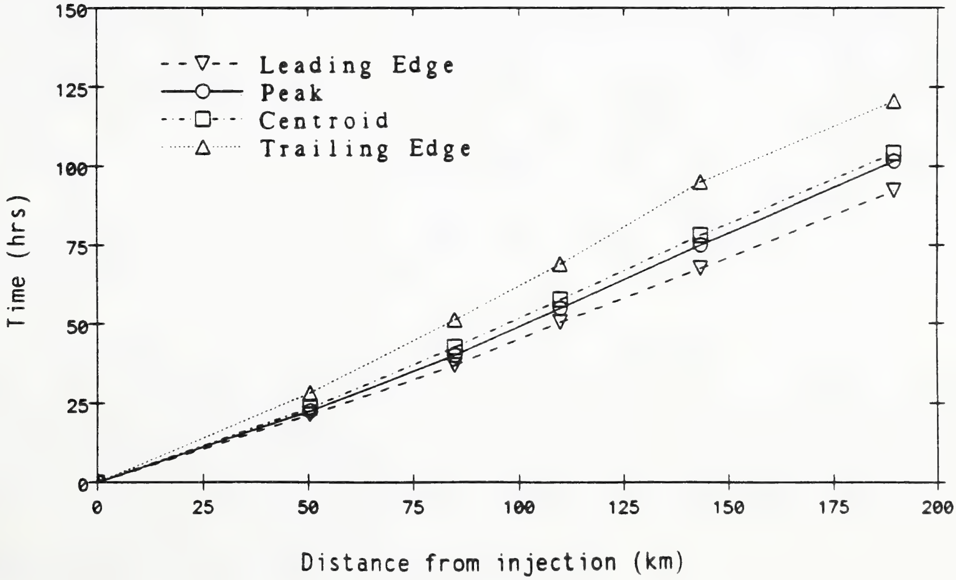


Figure 2b Growth of travel times with distance from injection, Shandro to Meridian.

of the storage and release of dye from stagnant areas. Therefore, the velocity of the peak should be used to calculate the hydraulic characteristics of a river reach.

Generalization of the hydraulic characteristics measured at the individual sites into reach-averaged characteristics for each of the subreaches was done by defining the mean velocity, U for each subreach as x/t_p, where x is the reach length and t_p is the time it takes for the peak of the dye cloud to pass through the reach. The resultant subreach mean velocities are given in table 4.

Using the time of travel of the peak to determine the mean velocity may lead to underestimating the time of travel if mixing across the channel is not fully established. That is, the dye moves primarily in the zone of high velocity and, hence, the velocity is over estimated because the entire flow is not represented. To estimate the magnitude of this measurement error in the initial subreach, the time of travel between Shandro and Duvernay was measured twice, once at the beginning of a test reach and once at the end of a test reach. Times of travel could not be compared directly because the discharges were not the same for both tests; however, velocities could be compared assuming the channel roughness remained relatively constant. The velocity in the initial subreach was found to be overestimated by about 11%. The velocity in the initial subreach between Edmonton and Fort Saskatchewan is likely overestimated by less than this value because three, rather than two, injection points were used, thereby spreading the dye more quickly over the channel width.

The mean velocity and the adopted discharge, Q were used to determine the flow area, A, for each subreach. From the flow area and top width, the mean depth, d, and the hydraulic radius, A/W, could be calculated. From these, Manning's roughness, n_o, was determined by:

$$[1] \qquad n_o = ((A/W)^{2/3} AS^{1/2})/Q$$

where S is the average water surface slope. Table 4 summarizes the

Table 4 Summary of average hydraulic characteristics in late winter for each subreach.

Subreach	**Reach Length** (km)	**Vel- ocity** (m/s)	**Dis- charge** (m^3/s)	**Slope**	**Top Width** (m)	**Flow Depth** (m)	**Manning's Roughness**
Edmonton -Ft. Saskatchewan	36.3	0.61	124	0.000359	170	1.19	0.035
Ft. Saskatchewan -Vinca	29.6	0.70	132	0.000332	200	0.95	0.025
Vinca -Waskatenau	25.7	0.66	142	0.000542	200	1.08	0.037
Waskatenau -Pakan	28.0	0.72	161	0.000383	187	1.20	0.031
Pakan -Shandro	27.2	0.56	168	0.000397	190	1.58	0.048
Shandro -Duvernay	50.3	0.56	156	0.000356	210	1.33	0.041
Shandro -Duvernay	50.4	0.62	152	0.000356	210	1.16	0.034
Duvernay -Myrnam	34.2	0.54	127	0.000216	190	1.23	0.031
Myrnam -Elk Point	25.2	0.47	108	0.000218	240	0.96	0.031
Elk Point -Heinsburg	33.5	0.47	112	0.000465	198	1.22	0.053
Heinsburg -Meridian	46.3	0.49	130	0.000198	212	1.26	0.034

results.

Manning's roughness was found to vary from 0.025 to 0.053. This range of roughness is higher than the open water roughness of 0.025 given by Kellerhals, Neill and Bray (1972) for flood discharges. This increase in roughness for low flow conditions is likely due to the increased effect of channel bed forms on the flow. That is, the non-uniform nature of pool and riffle sequences will cause an apparent increase in the roughness.

Beltaos and Anderson (1979) measured a velocity of 0.64 m/s between Fort Saskatchewan and Waskatenau for a tracer dye study performed at a discharge of 142 m^3/s. The Manning's roughness calculated from these values is 0.031, the same as the value found in this same reach during the present study with a discharge of 137 m^3/s.

3.2 Generalized Travel Times

The travel times for any given discharge are related to the mean velocity of the flow. Because the mean velocity varies monotonically with discharge in most cases, the measured travel times or velocities are only valid for the discharges at which the measurements were carried out.

The extrapolation to other discharges can be made by combining the equation of continuity:

$$[2] \qquad U = Q/Wd$$

with a roughness equation such as the Manning equation:

$$[3] \qquad Q = (1/n_o)\ R^{2/3}\ W\ d\ S^{1/2}$$

for which all the variables have been defined previously.

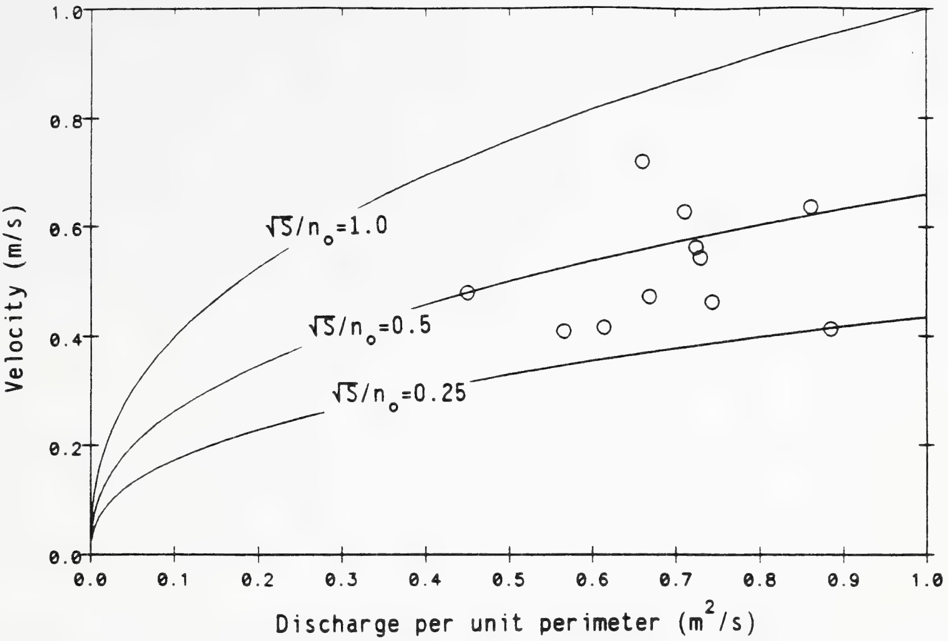


Figure 3 Relationships between mean velocity and discharge per unit width for the North Saskatchewan River.

It should be noted that for a wide, ice free channel, the hydraulic radius, R, is given by:

$$[4] \qquad R = A/W = d$$

Combining equations [2], [3], and [4] produces equation [5] which defines the mean velocity in terms of the width, the slope and the composite roughness

$$[5] \qquad U = (Q/W)^{0.4} \, (S^{0.5}/n_o)^{0.6}$$

Thus for a given river reach, with known values of S, W and n_o, the velocity, and hence the travel time, can be obtained for any given discharge. Figure 3 shows equation [5] in graphical form along with the test results. The curves show the general trend of increasing velocity

with increasing discharge for various values of slope and roughness. The data fits equation [5] exactly because a form of the equation was used to calculate the composite roughness.

The above analysis assumes that the composite roughness is constant for all flows. However, it can increase significantly with decreasing discharge as the flow depth decreases in relation to the variations in the channel bottom. If this relationship is approximated by

$$n_o = a\ Q^{-b} \tag{6}$$

then equation [5] becomes

$$U = C\ Q^{(0.4+0.6b)} \tag{7}$$

where C is a function of the shape and slope of the channel. If travel times are required at flood discharges, it may be necessary to perform additional travel time measurements at other discharges to define the exponent b. On the North Saskatchewan River, variations in roughness due to changes in discharge should be minor during the low flow period in late summer and early autumn because the river is regulated.

4.0 DISPERSION ANALYSIS

The tracer dye studies which were done to measure the hydraulic characteristics of the North Saskatchewan River can also be used to measure the rate of longitudinal dispersion, the process by which concentrations are reduced as the pollutant cloud spreads along the length of the channel. This longitudinal dispersion rate can be used to model or predict the extent of toxic concentrations downstream from an accidental chemical spill.

4.1 Reach-average Hydraulic Characteristics

Reach-average hydraulic characteristics, along with the data obtained in the tracer dye tests, are required to determine the nature of longitudinal dispersion in the North Saskatchewan River. Reach-average velocities can be obtained from the slope of the time-to-peak versus distance data for each reach as seen in figure 2. Velocities were quite consistent in both test reaches. Reach-average values of slope and width were calculated from the subreach values given in table 3. Reach-average flow depths were calculated from the average discharge, velocity and widths for each reach. All these hydraulic characteristics are given in table 5.

4.2 Mixing Zones

4.2.1 Vertical Mixing

The mixing process in rivers begins as a three-dimensional process but the pollutant concentration quickly becomes uniform over the depth. According to Elhadi et al. (1984), vertical variations in concentration are less than 2% at a distance L_v downstream from a source located at mid-depth when

$$[8] \qquad L_v = 1.8\ d\ U/U_*$$

where U_* is the shear velocity defined by

Table 5 Reach-average hydraulic characteristics.

Reach	Discharge (m^3/s)	Slope	Width (m)	Velocity (m/s)	Depth (m)	Shear Velocity (m/s)	Manning's Roughness
Edmonton-Duvernay	150	0.000389	200	0.64	1.18	0.067	0.035
Shandro--Meridian	128	0.000294	200	0.54	1.19	0.059	0.036

[9] $$U_* = (gRS)^{1/2}$$

in which g is the acceleration due to gravity.

Equation [8] estimates the vertical mixing length for an injection at mid-depth; however, both injections were near the surface. The mixing length should, therefore, be four times greater than that given by equation [8] (Elhadi et al., 1984). The vertical mixing lengths were approximately 80 m for both the injections on the North Saskatchewan River (table 6). Thus, it can be assumed that vertical mixing is instantaneous compared to the total reach lengths.

4.2.2 Transverse Mixing

Once the pollutant concentration becomes uniform over the depth, the mixing can be treated as a two-dimensional process. Further downstream, the pollutant concentration becomes uniform over the width of the channel as well. Transverse mixing is essentially complete at a distance L_t from a source located at mid-width where

[10] $$L_t = (0.1U/\epsilon_z)(W)^2$$

(Fischer et al., 1979) where ϵ_z is the transverse mixing coefficient usually estimated from

Table 6 Summary of mixing lengths for single centerline injection.

Reach	Reach Length (km)	Vertical Mixing Length (m)	Transverse Mixing Length (km)	Estimated Linear Mixing Length, $\alpha_L=1.0$ (km)
Edmonton-Duvernay	197.1	80	120	320
Shandro-Meridian	189.6	79	116	308

[11] $\epsilon_z = k_t d U_*$

When equations 10 and 11 are combined the result is

[12] $L_t = (0.1/k_t)\ (U/U_*)\ (W^2/d)$

Values of k_t normally range between 0.4 and 0.8 for natural streams (Fischer et al, 1979); however, Beltaos and Anderson (1979) measured ϵ_z in the North Saskatchewan River between Edmonton and Vinca and found k_t to be 0.17.

Yotsukura and Cobb (1972) introduced a parameter, k_p, which varies with the position of the source in the section and the degree of mixing

[13] $L_t = 1/(k_p k_t)\ (U/U_*)\ (W^2/d)$

Values of this position parameter for various fractions of cumulative discharge across a section and 95% complete mixing can be obtained from table 7.

The transverse mixing lengths listed in table 5 were calculated using equation 13 with k_p = 15.7 which corresponds to a single injection in the center of the channel. These lengths define the points where

Table 7 Position parameters for various fractions of cumulative discharge across a section and 95% complete mixing.

Fraction of Cumulative Discharge from Nearest Bank	Position Parameter
0.0	3.8
0.1	3.9
0.2	4.5
0.3	5.8
0.4	7.2
0.5	15.7

mixing is 95% complete. In the actual tests, however, multiple injections were used to reduce the length required for transverse mixing.

At Shandro, two injections were used, each at one-third of the channel width. This corresponds to 0.2 and 0.5 of the cumulative discharge distribution from the left bank and, from table 7, values for k_p of 4.5 and 15.7 respectively. Transverse mixing lengths for these injections individually are 403 km and 116 km respectively. Mixing to the nearest bank from each injection, however, will occur before transverse mixing is complete. Still, the left bank concentration will be higher than the right bank because the discharge in the left zone was less than that for the right zone. After this point, the only transverse mixing that will occur will be the leveling of the concentrations between the two zones.

To calculate these shorter mixing lengths, it is assumed that the injections occur at the center of a streamtube with a width twice the distance from injection point to the nearest bank. For $q/Q = 0.2$, this width is $2(0.2*200) = 80$ m and for $q/Q = 0.5$, the width is $2(0.5*200) = 200$ m. Using these widths and $k_p = 15.7$ for a centerline injection, the transverse mixing lengths become 64 km and 116 km respectively (table 8). Hence, after 116 km, the river has two completely mixed concentration zones which are slowly equalizing.

Table 8 Transverse mixing lengths for multiple injections.

Location	Cumulative Discharge from nearest bank	Position Parameter	Total Transverse Mixing Length (km)	Effective Width (m)	Mixing Length to nearest bank (km)
EDMONTON					
Left side	0.1	3.9	482	40	4.8
Centerline	0.3	5.8	324	120	43
Right side	0.2	4.5	418	80	19
SHANDRO					
Left side	0.2	4.5	403	80	64
Right side	0.5	15.7	116	200	116

At Edmonton, three injection points dividing the width uniformly were used to reduce the initial concentrations. This resulted in cumulative discharges of 0.1, 0.3, and 0.8 from the left bank. The transverse mixing lengths for these injections are given in table 8. Total transverse mixing does not occur in the 198.1 km test reach; however, within 50 km the dye is fully mixed to the banks. There is still a concentration gradient from one bank to the other after this distance but it can be ignored if cross-section average values are used in the analysis.

4.2.3 Linear Dispersion

When transverse mixing is complete, further mixing is due to longitudinal dispersion, the process which increases the spread of pollutant along the channel length as the pollutant travels downstream. Data from a large number of field studies by numerous investigators indicate that the onset of Fickian dispersion is delayed for some distance downstream after transverse mixing is completed (Beltaos, 1978). In this intermediate zone, differential advection and variations

in channel geometry cause longitudinal dispersion to occur more quickly than predicted by the Fickian dispersion model discussed in the following section. The field measurements suggest that in this zone the standard deviation of the time-concentration distribution, σ_t, grows linearly with distance; hence, this type of dispersion is called 'Linear' dispersion.

The location of the transition from Linear dispersion to Fickian dispersion can be estimated using

$$[14] \qquad L_L = \alpha_L(U/U_*)(W^2/d)$$

where α_L is a factor varying between 0.48 and 1.8 depending on the degree of channel irregularity (Elhadi et al., 1984). The transition occurs between L_L and $3L_L$, however, for practical purposes, the transition can be assumed to occur at $2L_L$. The Linear mixing length can be estimated for single injections by assuming that $\alpha_L = 1.0$. Estimated values of L_L are given in table 6 along with the other single injection mixing lengths.

Approximate values of Linear mixing lengths for multiple injections can be obtained by assuming each injection stays within its own streamtube. Hence, for two injection points the effective width is one-half of the river width and for three injection points the effective width is one-third of the river width. These multiple injection linear mixing lengths are much shorter than those for single injections because the mixing lengths are proportional to width squared. Using this procedure, the estimated value of L_L for the Edmonton injection is 36 km while for the Shandro injection it is 77 km.

No analytical solution exists for linear dispersion so Beltaos (1978) proposed the following empirical solution based on the existing data

$$[15] \qquad C = \frac{1}{\sqrt{2\pi\beta}} \frac{MU}{Qx} \left[\frac{Ut}{x} \exp\left[1 - \frac{Ut}{x}\right]\right]^{\frac{1}{\beta}}$$

where β is a parameter defined by

[16] $$\beta = \left[\frac{\sigma_t}{U/x}\right]^2$$

The calculation of β from measured concentrations can be simplified by defining the pollutant spread in terms of the half-duration, ΔT rather than the standard deviation, σ_t. This eliminates the problems in evaluating σ_t due to incomplete measurements on the falling limb. The half-duration is defined as the period of time during which the concentration is greater than one-half of the peak concentration (figure 4). The half-duration, ΔT of the empirical curve described by equation [15] is equal to 2.36 σ_t; therefore, β can be defined in terms of ΔT

[17] $$\beta = 0.18\left[\frac{\Delta T}{U/x}\right]^2$$

4.2.4 Fickian Dispersion

The final mixing process is termed Fickian dispersion. This process can be modeled using the one-dimensional mixing equation

[18] $$\frac{\delta C}{\delta t} + U\frac{\delta C}{\delta x} = D\frac{\delta^2 C}{\delta x^2}$$

which, for a mass, M instantaneously released throughout a cross-section, has the solution

[19] $$C = \frac{MU}{2Q\sqrt{\pi Dt}} \exp\left[-\frac{(x-Ut)^2}{4Dt}\right]$$

where C is the cross-sectional average concentration. The properties of this analytical solution indicate that the dispersion coefficient, D can be defined by

[20] $$D = \frac{U^3}{2}\frac{d\sigma_t^2}{dx}$$

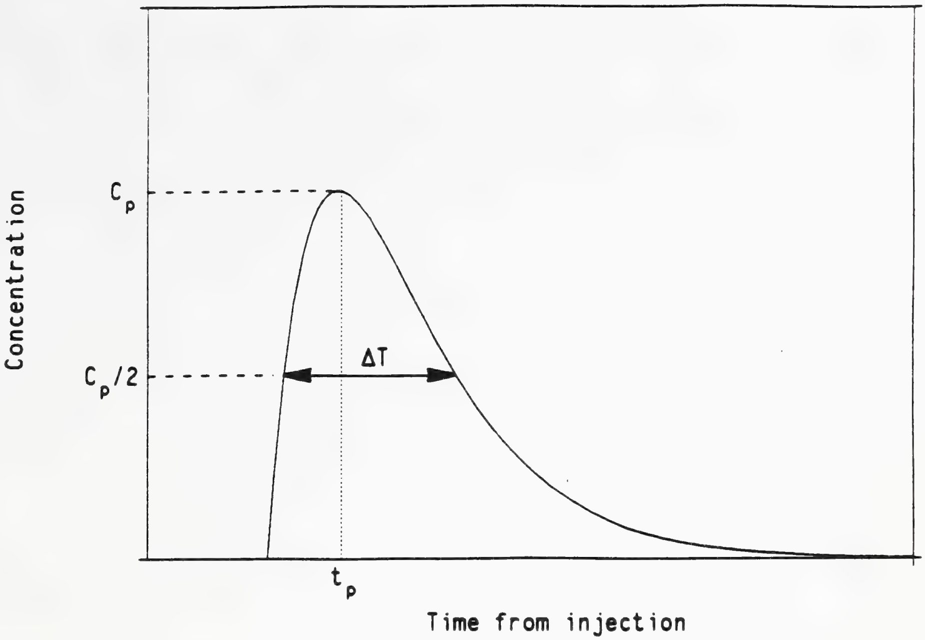


Figure 4 Definition sketch for variables describing time-concentration distributions

That is, the rate of change of the variance, σ_t^2 with distance is constant.

4.3 Dispersion Parameters

The dispersion parameters discussed in the previous sections can be evaluated using variables describing the cross-sectional average time-concentration distributions. The variables describing these distributions at each location are: time-to-peak, t_p; half-duration, ΔT; variance, σ_t^2; peak concentration, C_p; and mass recovery ratio, M/M_o. A summary of these variables for each location is given in table 9.

The Linear dispersion parameter, β can be evaluated using equation [17], that is, reach-average values of β for the North Saskatchewan River can be obtained from the slopes of the best-fit lines through the

half-duration versus time-to-peak data shown in figure 5. Values of β for the two test reaches are listed in table 10. These values of β are lower than the values measured under an ice cover (Van Der Vinne, 1991); however, they are consistent with the trend of increasing β with U_*/U shown in figure 6 (Beltaos, 1978).

The value of the Linear dispersion parameter for the Edmonton injection is also lower than the value of $\beta=0.0106$ found by Beltaos and Anderson (1979) for the reach between Fort Saskatchewan and Waskatenau under similar hydraulic under similar hydraulic conditions ($U_*/U=0.138$). The value for the present study may be lower because it was evaluated over a longer reach; however, the present study is more consistent with the trend shown in figure 6 for other open water Linear dispersion parameters reported by Beltaos (1978).

Values of D can also be evaluated from dye test data provided that the test reaches extend into the Fickian range. As stated in equation [20], σ_t^2 vs x is linear in the Fickian range and D is proportional to the slope of this line. Three data points are needed to establish that the trend is linear. The values of D calculated from slopes obtained from figure 7 are given in table 10. The dispersion coefficients measured in this study are consistent with values reported in the literature for channels of this width and roughness (figure 8).

Actual values, or at least lower limits, of L_L can also be obtained from figure 7. Beltaos (1978) defined L_L as the x-intercept of a straight line fitted through the σ_t^2 vs x data in the Fickian dispersion zone. Once L_L is evaluated, the actual value of α_L can be obtained from equation [14]. Values of both L_L and α_L for the test reaches are given in table 10.

The values of L_L given in table 10 are similar to the values estimated in section 4.2.3 but are less than the transverse mixing lengths given in table 8 because L_L is evaluated from cross-section average values. Thus, only average concentrations can be predicted before transverse mixing is complete.

Table 9 Summary of cross-section average time-concentration distribution variables.

Location	Distance from Injection (km)	Time to Peak (hrs)	Half-duration (hrs)	Variance (hrs^2)	Peak Concentration ($\mu g/L$)	Mass Recovery Ratio
Edmonton injection						
Ft. Saskatchewan	36.3	16.5	1.55	0.72	4.509	1.026
Vinca	65.9	28.3	3.86	3.70	1.440	0.830
Waskatenau	91.6	39.2	6.60	5.96	1.042	0.983
Pakan	119.6	50.0	7.68	11.66	0.720	0.926
Shandro	146.8	63.5	10.30	14.96	0.622	0.972
Duvernay	197.1	88.5	12.98	23.18	0.458	0.944
Shandro injection						
Duvernay	50.4	22.5	1.70	0.91	3.643	1.017
Myrnam	84.6	40.0	6.05	5.71	1.264	0.861
Elk Point	109.8	55.0	8.78	10.16	1.121	0.980
Heinsburg	143.3	75.0	12.10	18.20	0.662	0.945
Meridian	189.6	101.5	12.58	22.95	0.579	0.959

Table 10 Summary of dispersion parameters.

Reach	**Linear Dispersion Parameter** β	**Linear Mixing Length** L_L **(km)**	**Linear Mixing Length Factor** α_L	**Fickian Dispersion Coefficient** D **(m^2/s)**
Edmonton-Duvernay	0.00416	51.4	1.45	266
Shandro-Meridian	0.00353	47.2	0.61	168

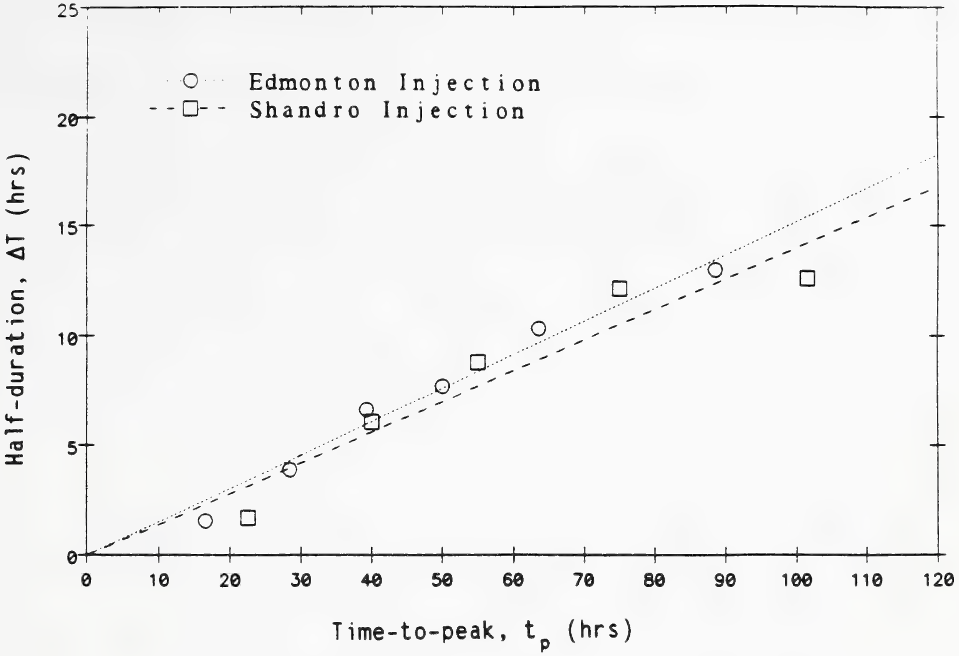


Figure 5 Variation of half-duration with time-to-peak from injection.

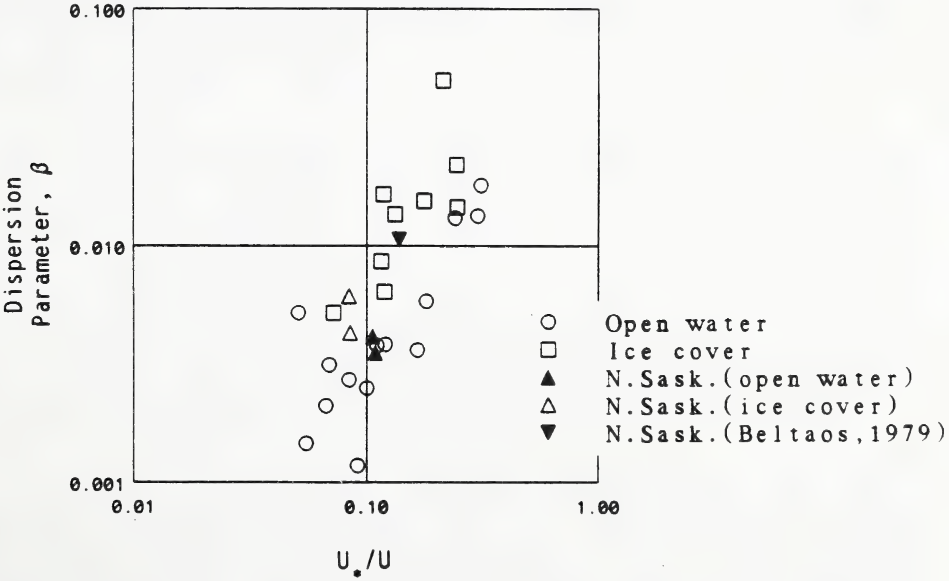


Figure 6 Variation of β for both open water and ice covered conditions (Beltaos, 1978).

4.4 Dispersion Model Predictions

4.4.1 Linear Dispersion

Time-concentration distributions were generated for each sample site using the linear dispersion model defined in equation [15]. These predicted distributions are plotted in figure 9 along with the cross-section average of the measured distributions. The major discrepancy between the measurements and the model predictions is in the magnitude of the peak concentrations. The model predicts peak concentrations slightly higher than the measured values.

An assumption in the model is that the dye is completely conserved but the mass recovery ratios plotted in figure 10 show that as much as 15% of the dye was undetected at some of the sample sites. This undetected dye may be lost due to chemical and physical processes or it may be due to inaccurate assumptions of discharge or water temperature. For example, the increase in mass recovery ratio between Fort Saskatchewan and Vinca is likely due to errors in the discharge estimates. If the model were modified to account for losses in mass, the predicted time-concentration distributions would match the measurements much more closely.

The peak concentrations predicted by the model may also be higher than the measured peaks because of the difference in shape between of the predicted and measured time-concentration distributions shown in figure 9. The more symmetrical curves predicted by the model have shorter durations, therefore the peaks would be higher even if the dye masses were the same. The model could be improved by making it predict the shape of the time-concentration distributions more accurately.

The times-to-peak of the predicted distributions are slightly different from the measured values as well. This difference is caused by the model using reach-average velocities rather than measured sub-reach velocities.

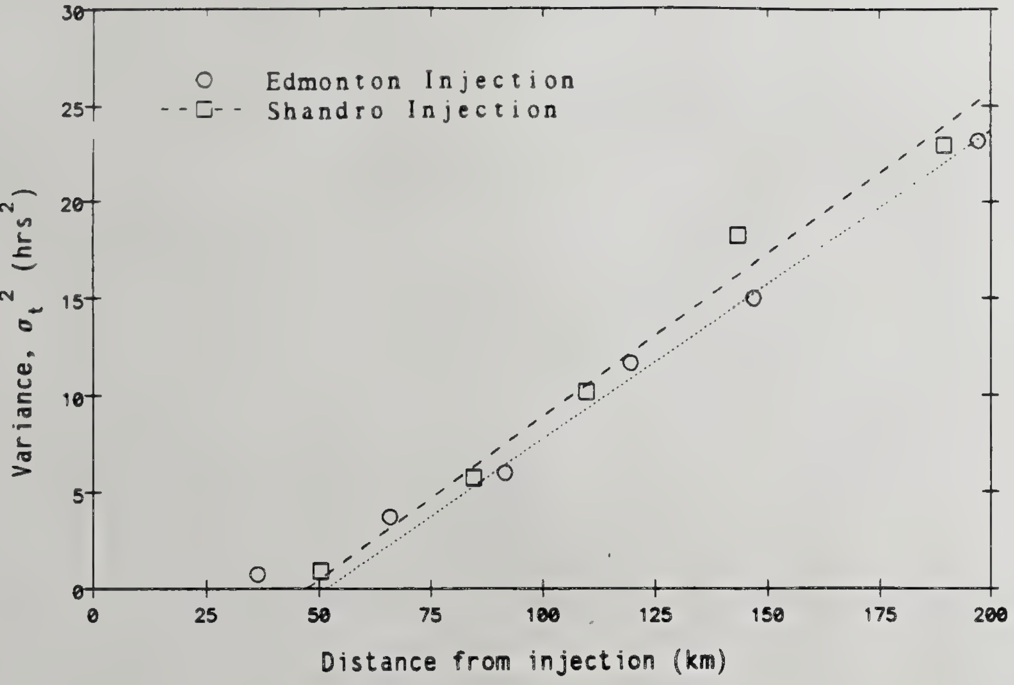


Figure 7 Increase in variance with distance from injection.

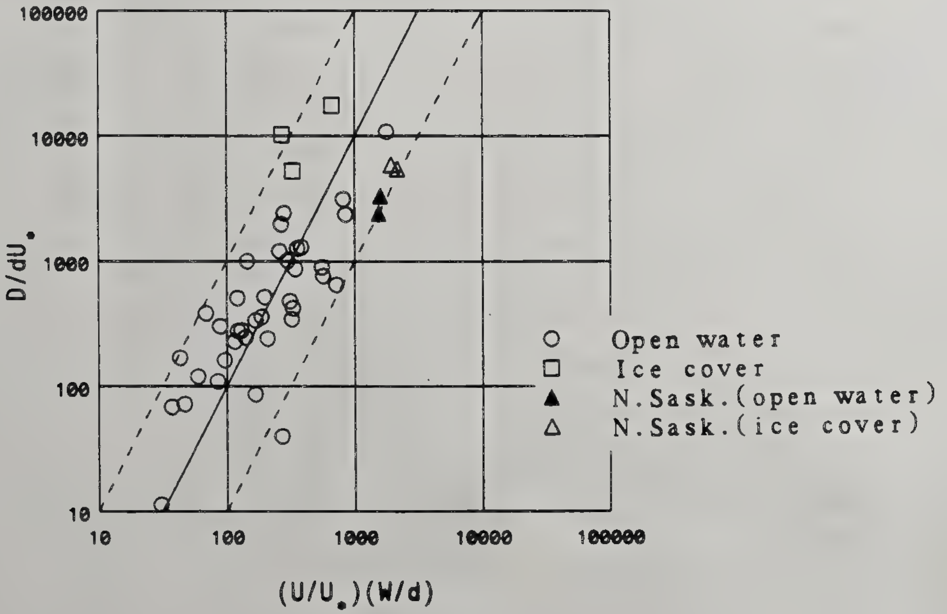
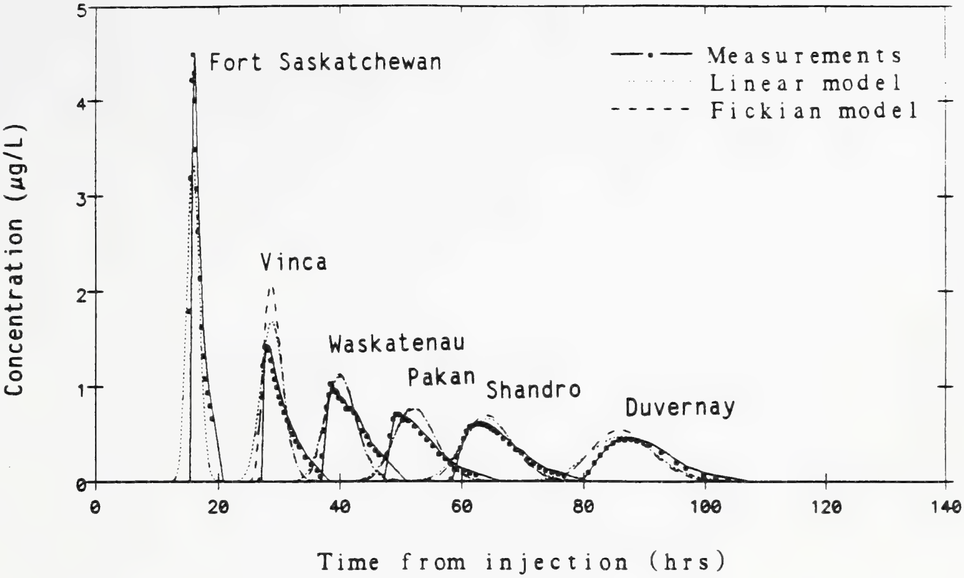


Figure 8 Variation of dimensionless dispersion coefficient (Beltaos, 1978).



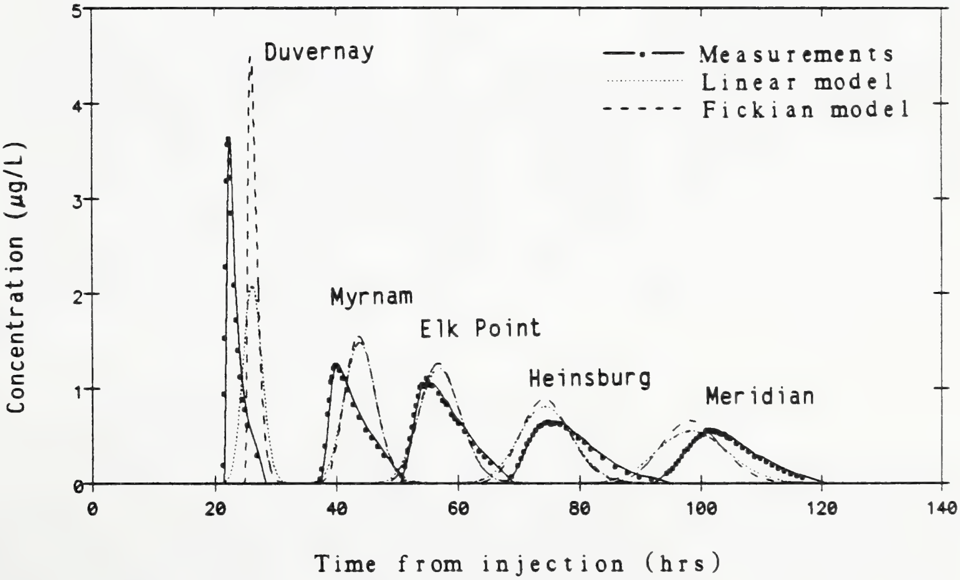


Figure 9 Comparison of measured time-concentration distributions with those predicted by the dispersion models.

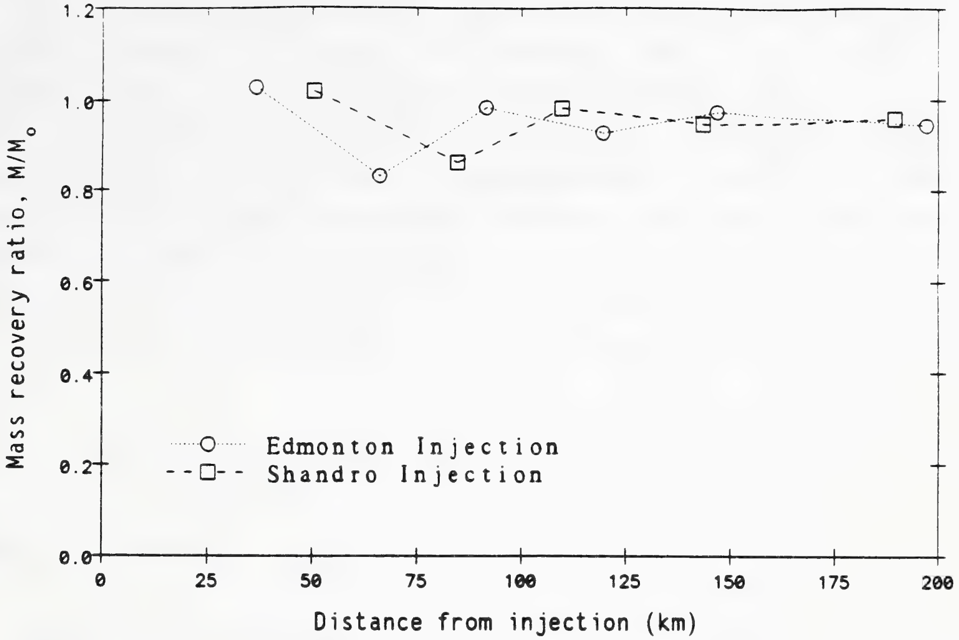


Figure 10 Variation in mass recovery ratio with distance from injection.

The model predictions are reasonable considering all the assumptions and approximations used to obtain the modeling parameters. The linear dispersion model can be used with confidence to predict concentrations downstream of accidental releases of pollutants as long as some margin for error is incorporated into the results. However, this model should only be used until the point where Fickian dispersion begins.

4.4.2 Fickian Dispersion

Elhadi et al (1984) state that once a pollutant cloud passes a point $3L_L$ away from the spill site, equation [19] should be used to predict concentrations. Equation [14] can be used to estimate L_L for single injections; however, this distance is so large for the North Saskatchewan River that Fickian dispersion would not occur until well into Saskatchewan.

In the case of the multiple injection tests done in this study, L_L can be estimated by dividing the channel width by the number of injections and using this reduced width in equation [14]. As well, Equation [19] cannot be used as it stands because its derivation assumed complete mixing across the section immediately upon injection. To make equation [19] suitable for modeling dispersion from sources other than completely mixed sources, it must be assumed that the pollutant is injected, fully mixed, at a virtual origin a distance L_L downstream from the actual injection. Thus equation [19] becomes

$$[21] \qquad C = \frac{MU}{2Q\sqrt{\pi D(t-t_o)}} \exp\left[- \frac{(x-U(t-t_o))^2}{4D(t-t_o)} \right]$$

where t_o is defined as L_L/U.

Predicted distributions using this modified Fickian dispersion model are shown in figure 9 along with those of the Linear model. All locations greater than L_L were modeled to show the inaccuracy of the model in the Linear dispersion zone. Note that the peaks predicted by the Fickian dispersion model are highest at both Vinca and Myrnam; however, by the end of the reaches, predictions from the two model are quite similar. If the reaches were extended, the Linear model would begin to overpredict dispersion while the Fickian model would be more accurate.

4.0 SUMMARY

Two tracer dye tests were carried out on the North Saskatchewan River between Edmonton and the Saskatchewan border. Discharges during the tests ranged from 108 m^3/s to 168 m^3/s. Velocities calculated from the travel times of the peak concentration ranged between 0.47 m/s and 0.72 m/s. Hydraulic roughnesses varied between 0.025 and 0.053. The extrapolation of these velocities is possible, provided some confidence can be placed on the adopted values of hydraulic roughness for the extrapolated conditions.

Two types of longitudinal dispersion occurred during the dye tests. First, after transverse mixing was completed, 'Linear' dispersion occurred, where the length of the dye cloud grew linearly with distance. After a transition period, the second type of longitudinal dispersion, Fickian dispersion, began where the length grew with the square root of distance.

The Linear dispersion parameter was found to be 0.00416 for the Edmonton injection and 0.0353 for the Shandro injection. The Fickian dispersion coefficient was found to be 266 m^2/s for the upper reach and 168 m^2/s for the lower reach. These values for dispersion are consistent with values reported in the literature for channels of similar width and roughness; however, they are lower than the values measured in the same reaches under an ice cover.

Once the loss of dye was taken into account, the major discrepancy between the results of the longitudinal dispersion models and the measurements was the shape of the concentration distributions. The models predicted much more symmetrical distributions than were actually observed.

The data from this tracer dye study and the previous winter's tracer dye study may also be used to study the effects of an ice cover on the hydraulic roughness of a river reach. A comparison of the travel time data from the two tests will detect any changes in the

reach-averaged hydraulic characteristics caused by the presence of an ice cover. Previous measurements of hydraulic roughness under an ice cover were done using point measurements and extrapolating to obtain reach-averaged values. The reach-averaged hydraulic roughnesses obtained from the tracer dye studies include the effects of large scale form roughness and frazil deposits as well as the local surface roughness.

The analysis of the data presented herein contributes to the information available on both the hydraulic and mixing characteristics of the North Saskatchewan River downstream of Edmonton. This information makes it possible to model the one dimensional mixing processes in the river during low flow periods. However, more information on transverse mixing is still required before pollutant transport in the two dimensional mixing zone can be modeled accurately. As well, the hydraulic and mixing characteristics defined by this study cannot be extrapolated to flood flows with any degree of accuracy. To obtain this information, it is recommended that:

(1) an additional tracer dye study be performed to define the hydraulic and mixing characteristics of the reach during high flows;

(2) the variations of the transverse mixing coefficient along the river be evaluated from existing data from all tracer dye studies done in the reach; and, if this is insufficient,

(3) additional constant head tracer dye studies be performed at critical sites such as sewage treatment plant outfalls to evaluate the transverse mixing coefficients required to model the two dimensional mixing of pollutants.

5.0 REFERENCES

Beltaos, S. (1978): An interpretation of longitudinal dispersion data in rivers. Transportation and Surface Water Engineering Division Report No. SWE-78/03, Alberta Research Council.

Beltaos, S., Anderson, M.D. (1979): Mixing characteristics of the North Saskatchewan River below Edmonton, Part I. Transportation and Surface Water Engineering Division Report No. SWE-79/01, Alberta Research Council.

Elhadi, N., Harrington, A., Hill, I., Lau, Y.L., and Krishnappan, B.G. (1984): River mixing - a state-of-the-art report. Canadian Journal of Civil Engineering, Vol. 11, No, 3, pp. 585-609.

Fischer, H.B., List, E.J., Koh, R.C., Berger, G.N., and Brooks, N.H. (1979): Mixing in inland and coastal waters. Academic Press, N.Y.

Kellerhals, R., Neill, C.R., and Bray, D.I., (1972): Hydraulic and geomorphic characteristics of rivers in Alberta. River Engineering and surface Hydrology Report No. 72-1, Alberta Research Council.

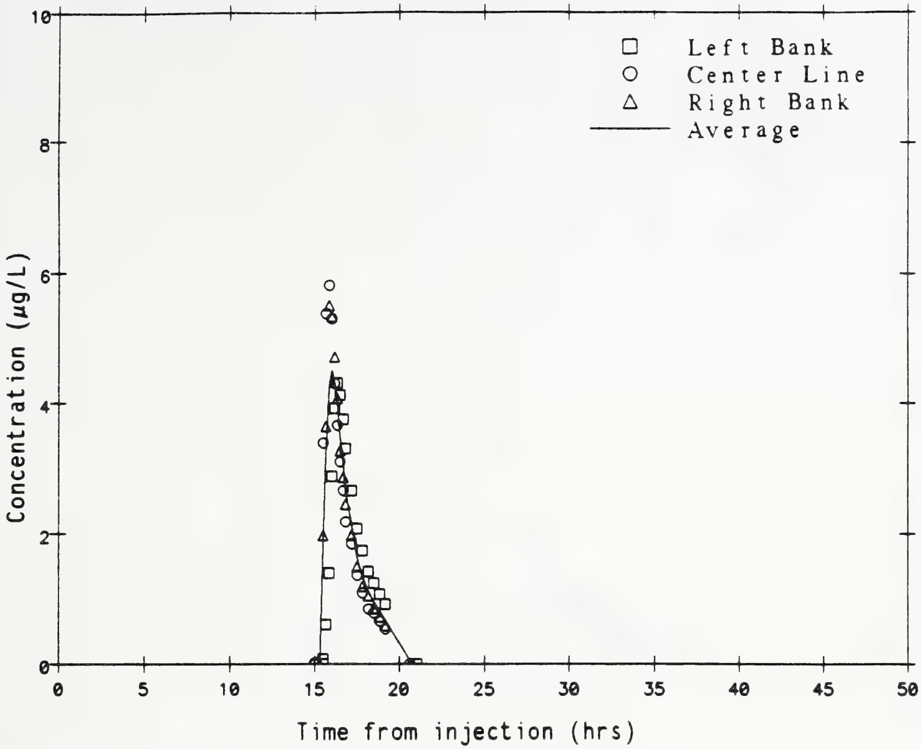
Van Der Vinne, G., (1991): Winter tracer dye studies on the North Saskatchewan River, Edmonton to Saskatchewan border. Surface Water Engineering Group Report No. SWE-04/91, Environmental Research and Engineering Department, Alberta Research Council.

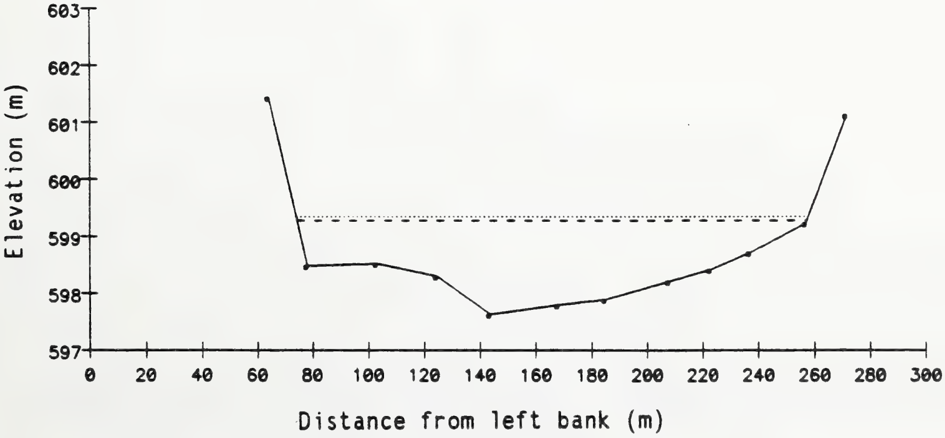
Yotsukura, N. and Cobb, E.D., (1972): Transverse diffusion of solutes in natural streams. USGS Prof. Paper 582C.

APPENDIX A

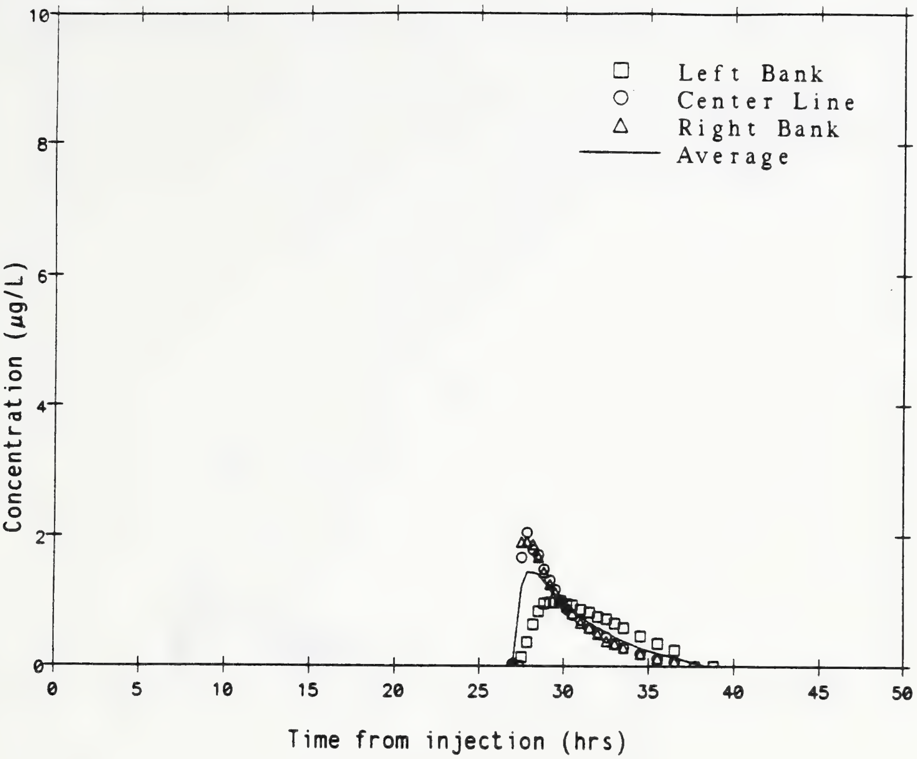
Time-Concentration Curves
and
Channel Cross-sections

Fort Saskatchewan

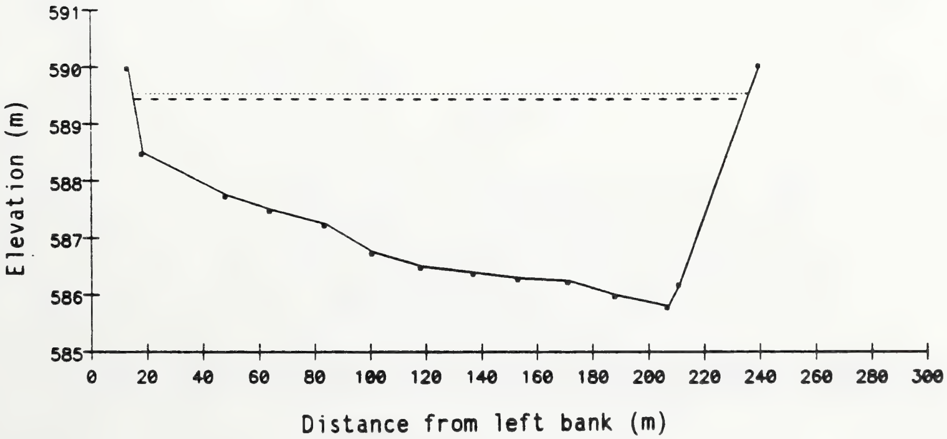




Vinca

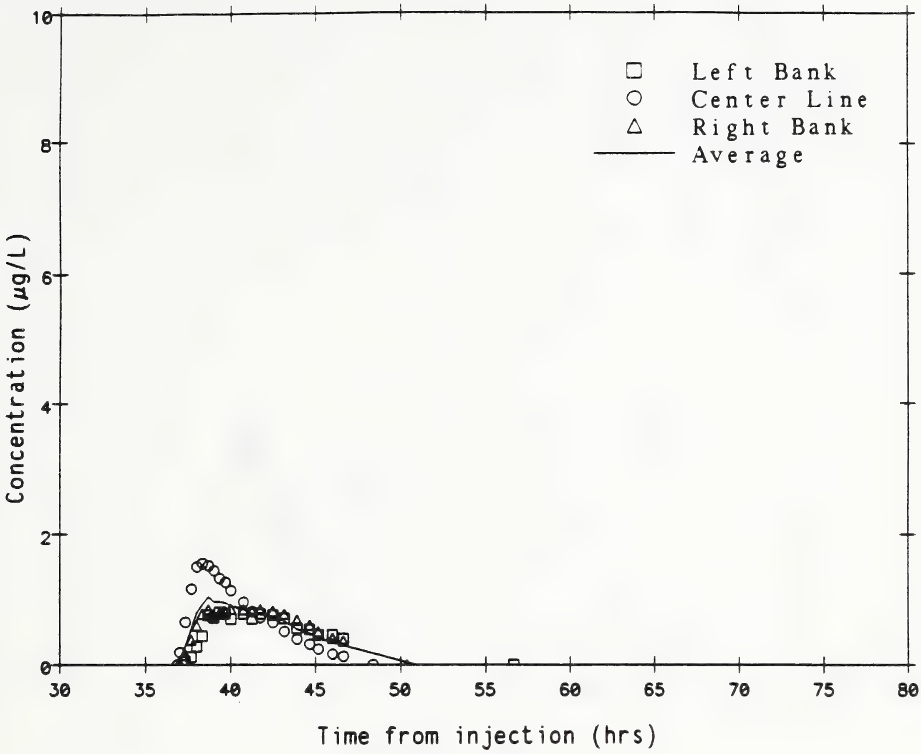


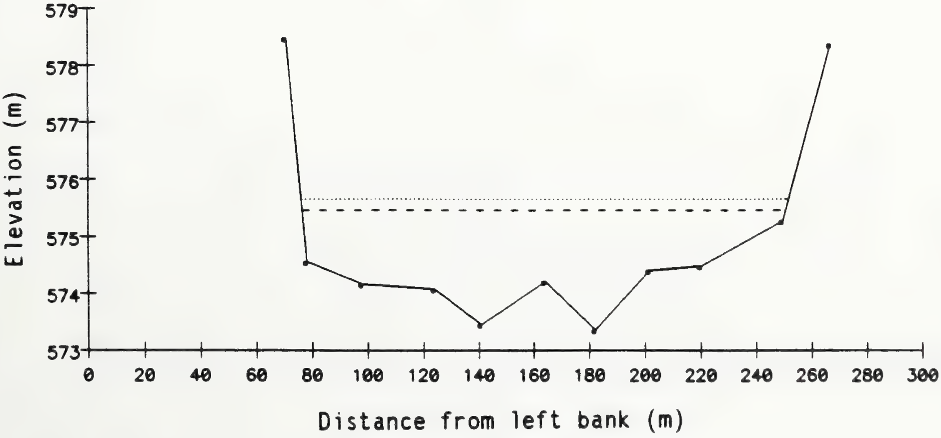
□ Left Bank
○ Center Line
△ Right Bank
Average
Concentration (µg/L)
0
2
4
6
8
10
0
5
10
15
20
25
30
35
40
45
50
Time from injection (hrs)



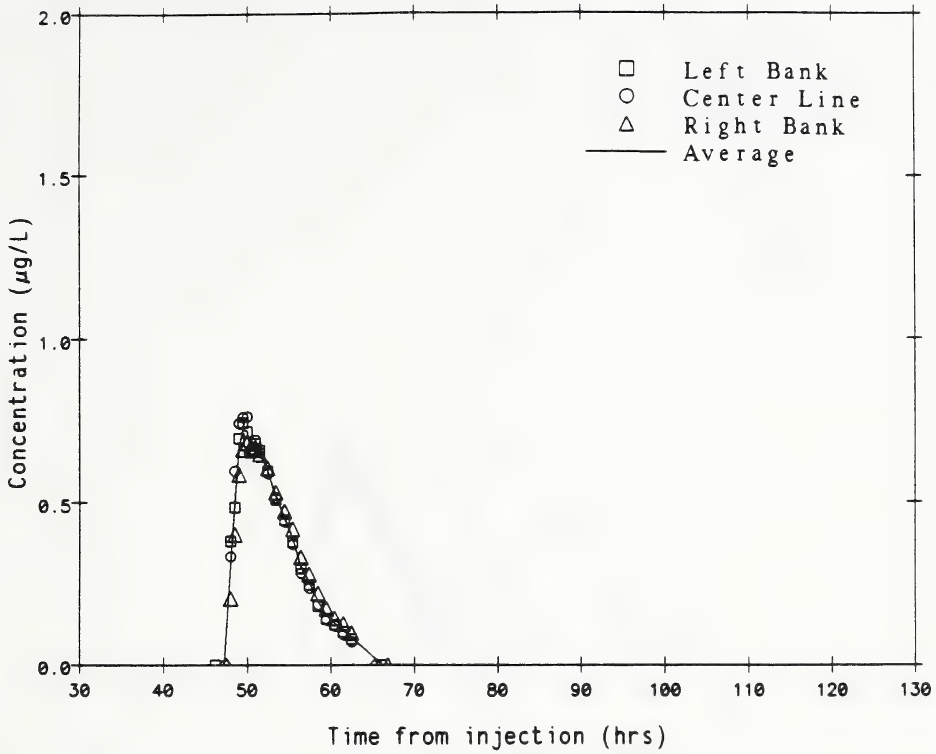
Elevation (m)
585
586
587
588
589
590
591
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Distance from left bank (m)

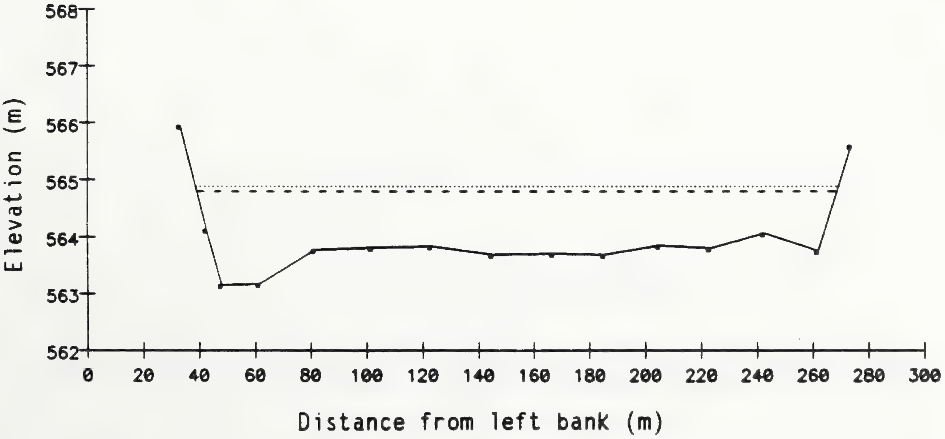
Waskatenau

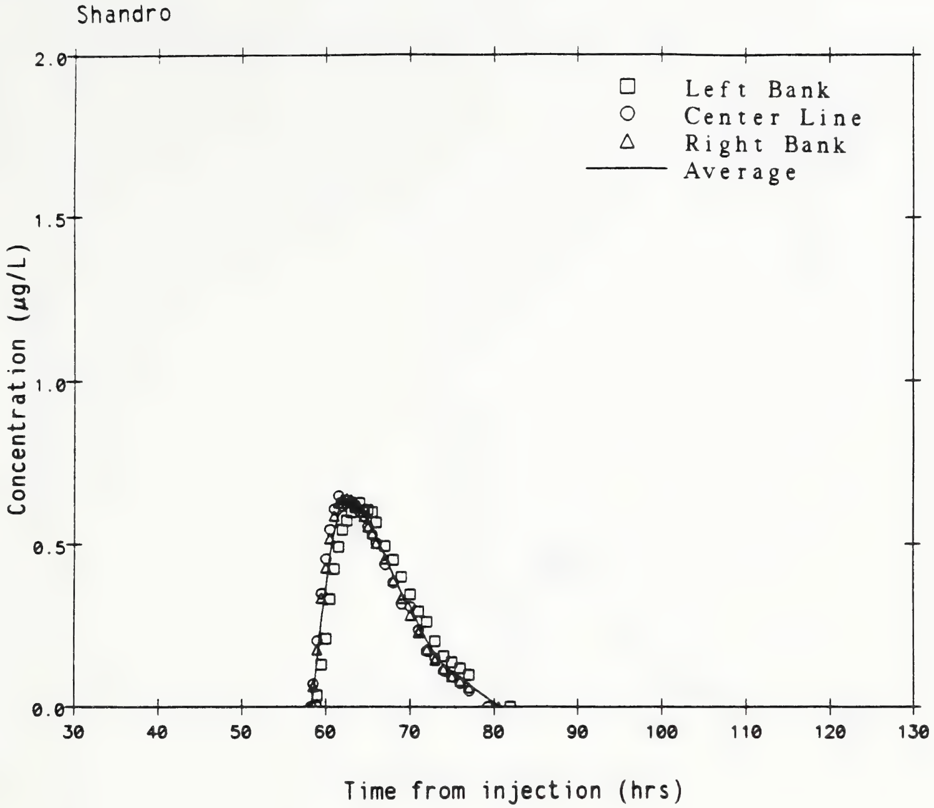

Left Bank
Center Line
Right Bank
Average
Concentration (µg/L)
0
2
4
6
8
10
30
35
40
45
50
55
60
65
70
75
80
Time from injection (hrs)

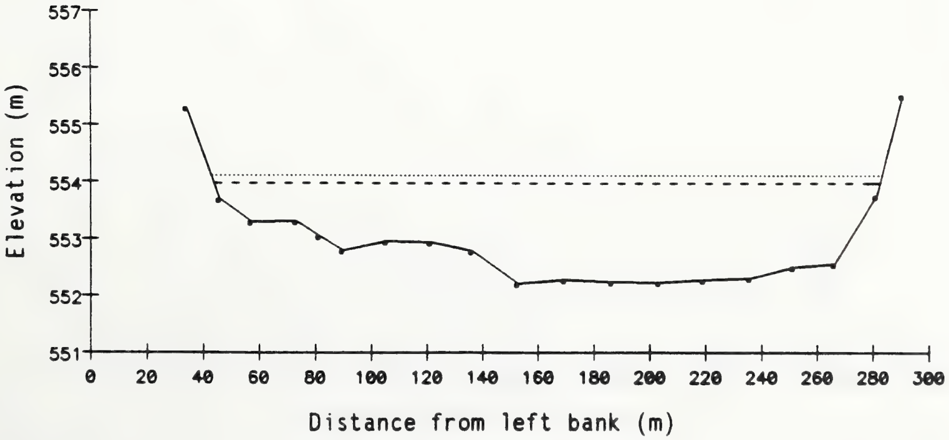

Elevation (m)
573
574
575
576
577
578
579
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Distance from left bank (m)

Pakan

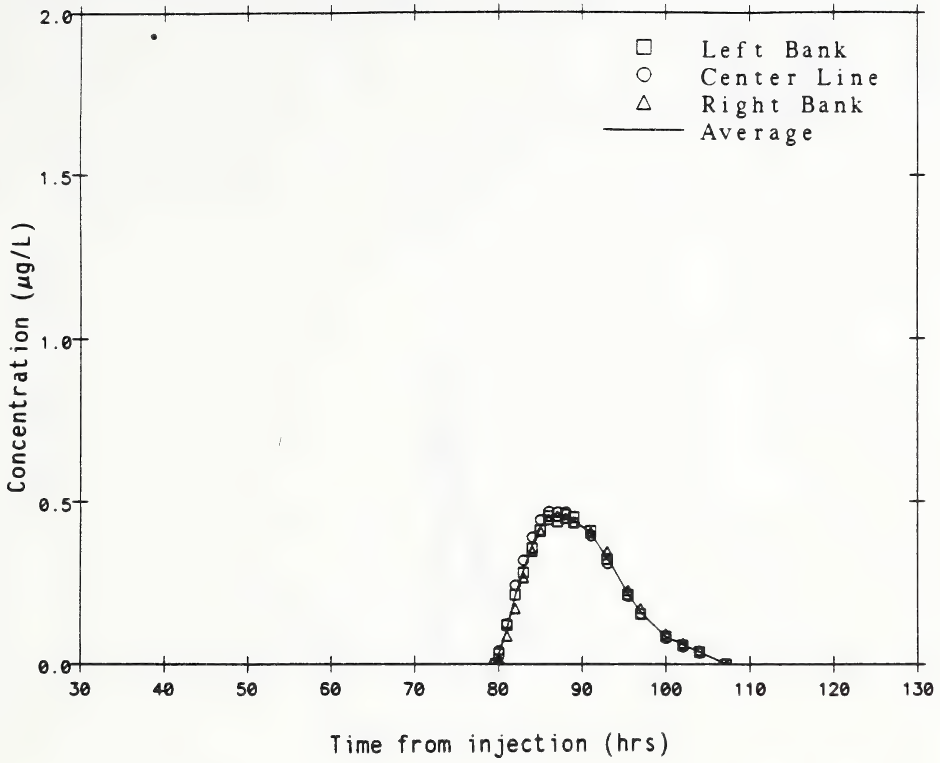

Left Bank
Center Line
Right Bank
Average
Concentration (µg/L)
2.0
1.5
1.0
0.5
0.0
30
40
50
60
70
80
90
100
110
120
130
Time from injection (hrs)


Elevation (m)
568
567
566
565
564
563
562
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Distance from left bank (m)

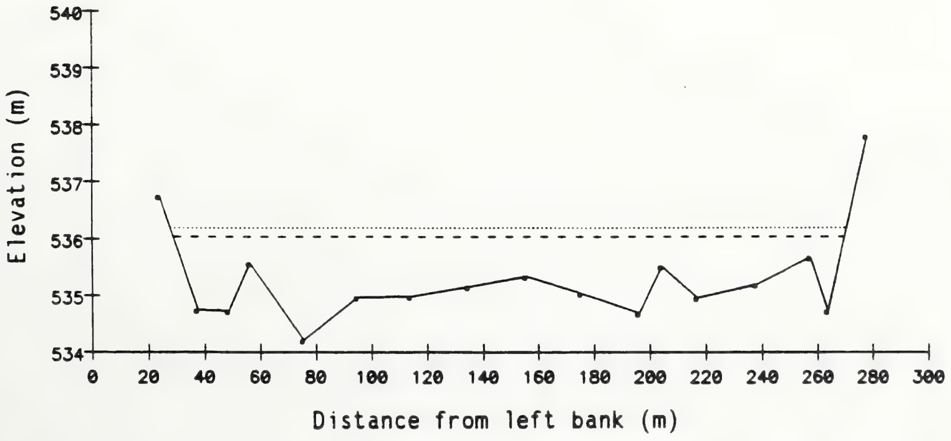

Shandro
Left Bank
Center Line
Right Bank
Average
Concentration (µg/L)
2.0
1.5
1.0
0.5
0.0
30
40
50
60
70
80
90
100
110
120
130
Time from injection (hrs)


Elevation (m)
557
556
555
554
553
552
551
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Distance from left bank (m)

Duvernay

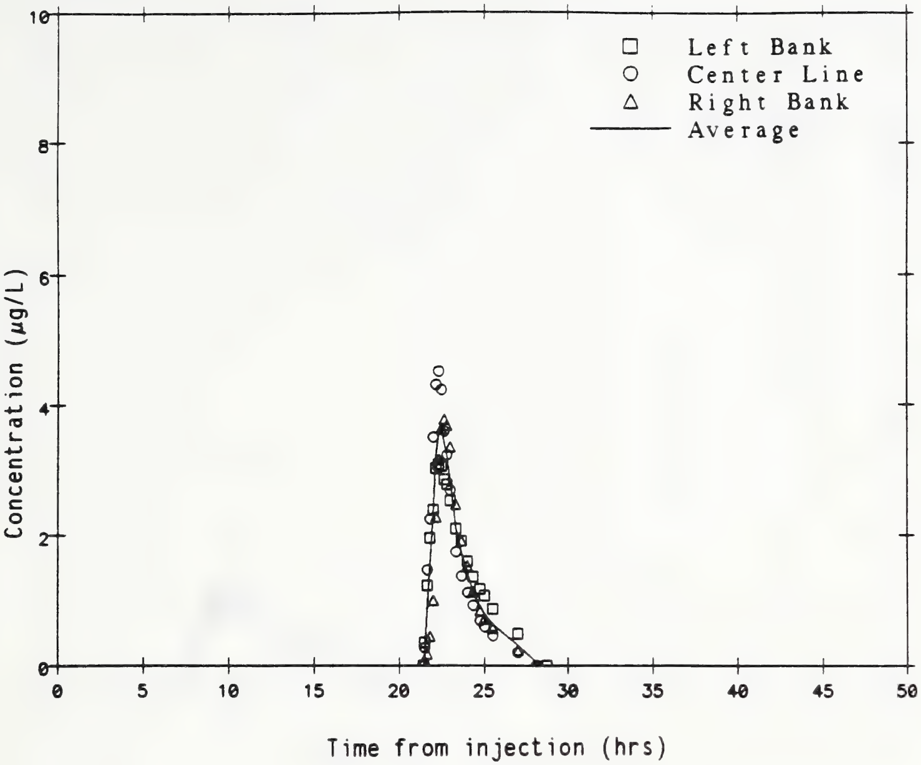


2.0
1.5
1.0
0.5
0.0
Concentration (µg/L)
□ Left Bank
○ Center Line
△ Right Bank
Average
30
40
50
60
70
80
90
100
110
120
130
Time from injection (hrs)

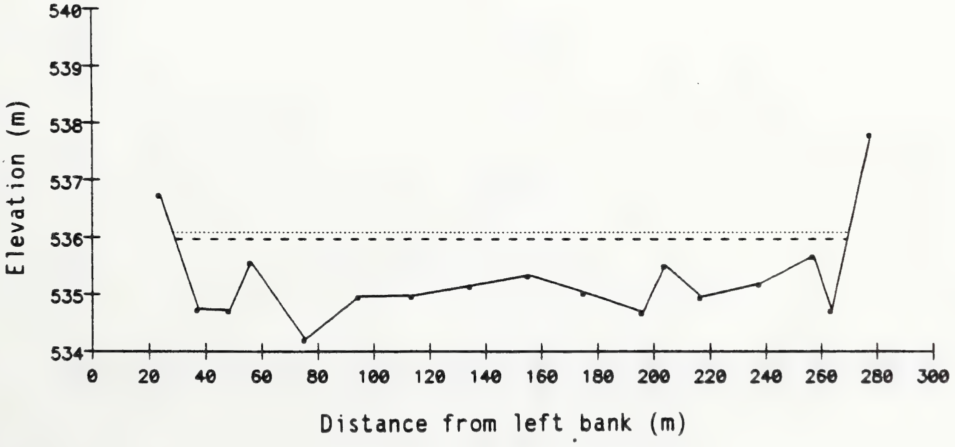


540
539
538
537
536
535
534
Elevation (m)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Distance from left bank (m)

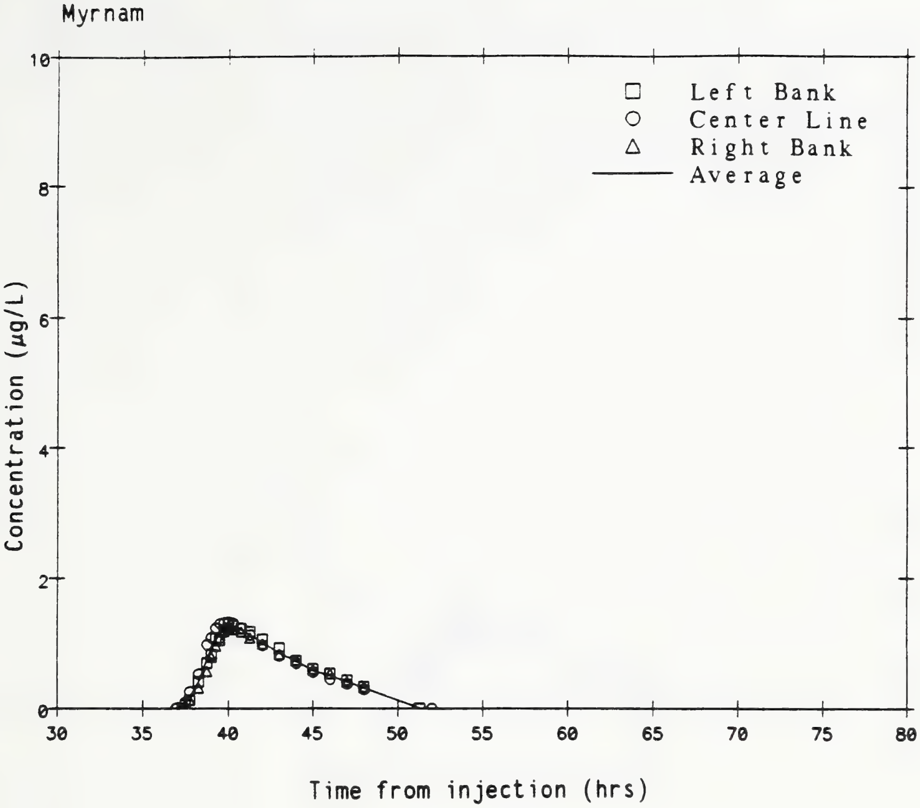
Duvernay

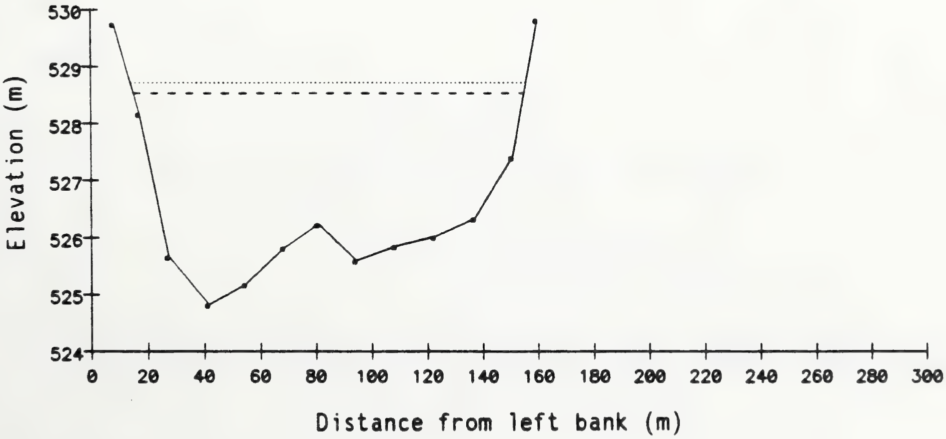


10
8
6
4
2
0
Concentration (μg/L)
0
5
10
15
20
25
30
35
40
45
50
Time from injection (hrs)
□ Left Bank
○ Center Line
△ Right Bank
Average

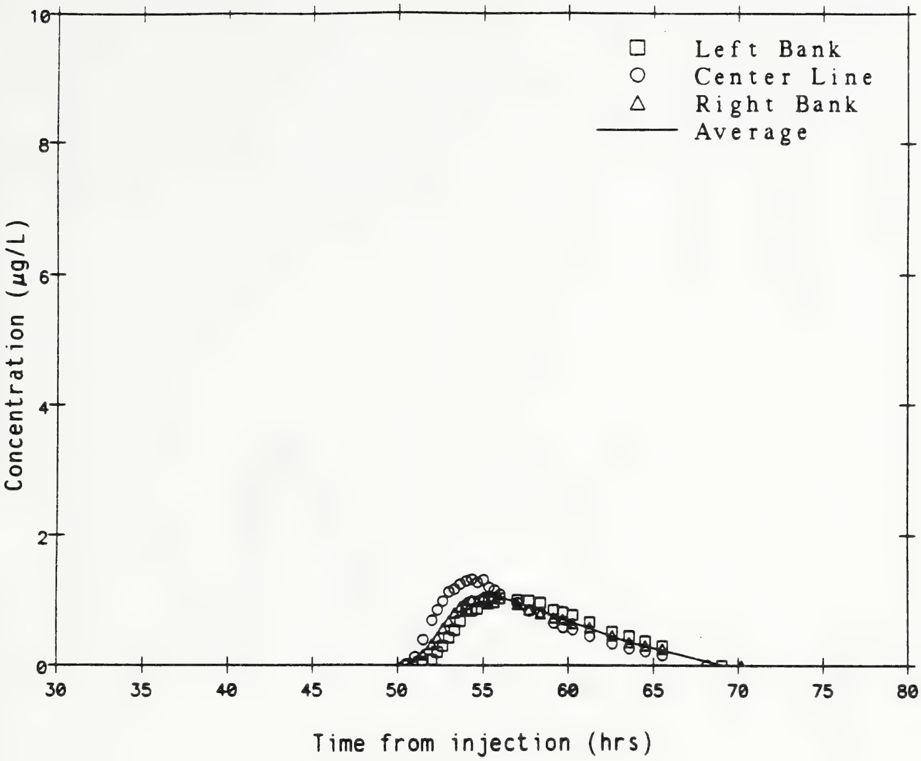


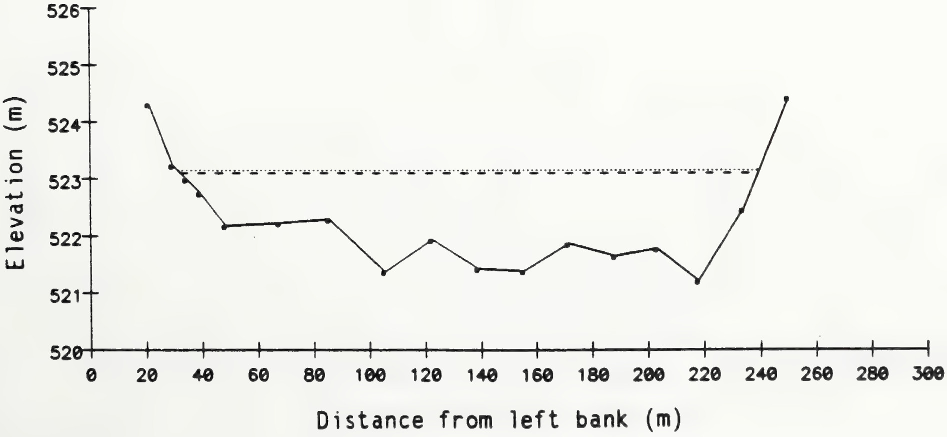
540
539
538
537
536
535
534
Elevation (m)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Distance from left bank (m)

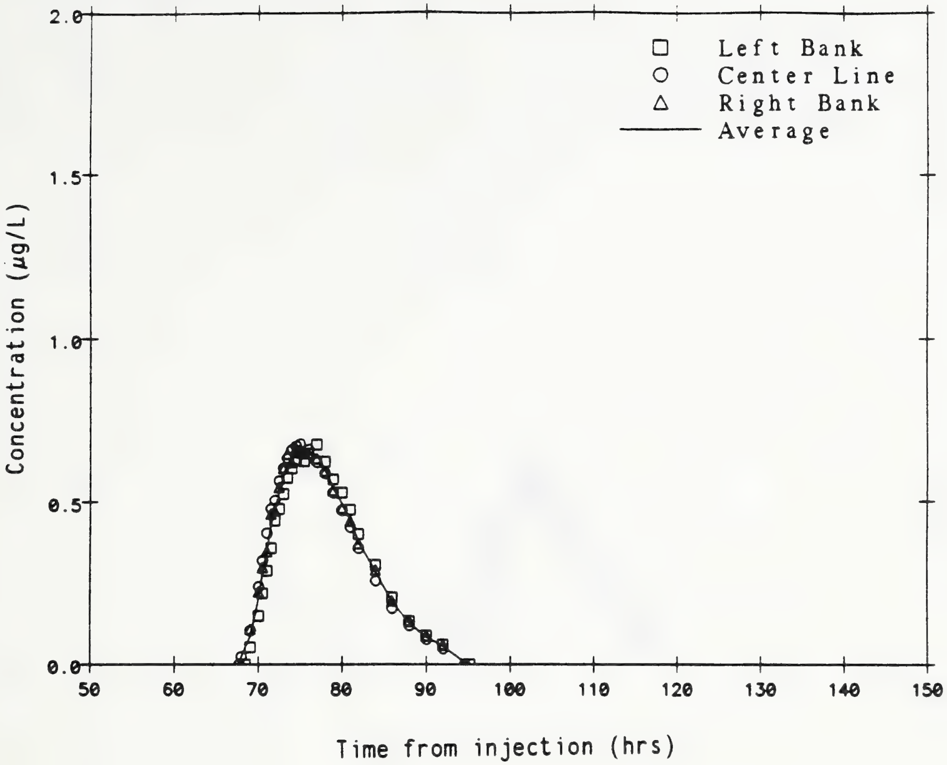

Myrnam
□ Left Bank
○ Center Line
△ Right Bank
Average
Concentration (µg/L)
0
2
4
6
8
10
30
35
40
45
50
55
60
65
70
75
80
Time from injection (hrs)

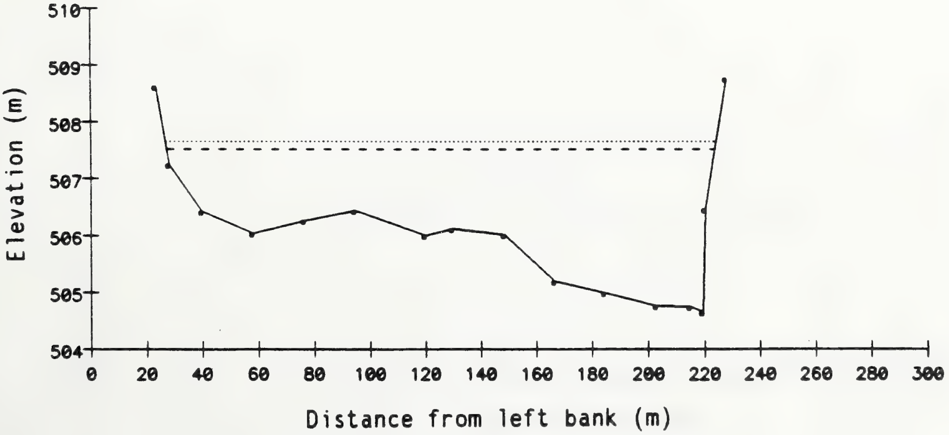

Elevation (m)
524
525
526
527
528
529
530
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Distance from left bank (m)

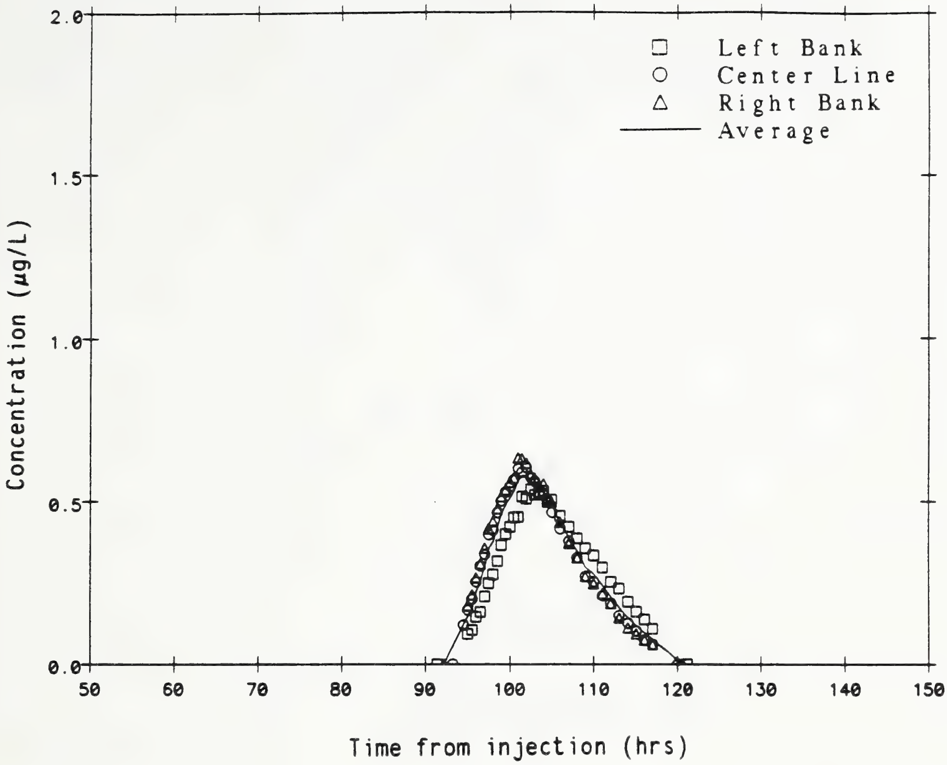
Elk Point


Left Bank
Center Line
Right Bank
Average
Concentration (μg/L)
0
2
4
6
8
10
30
35
40
45
50
55
60
65
70
75
80
Time from injection (hrs)


Elevation (m)
520
521
522
523
524
525
526
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Distance from left bank (m)

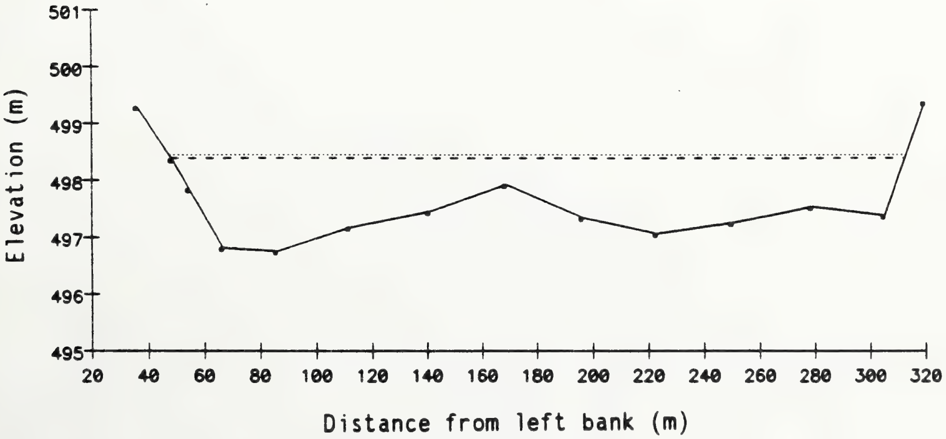

Heinsburg
□ Left Bank
○ Center Line
△ Right Bank
Average
Concentration (µg/L)
2.0
1.5
1.0
0.5
0.0
50
60
70
80
90
100
110
120
130
140
150
Time from injection (hrs)


Elevation (m)
510
509
508
507
506
505
504
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Distance from left bank (m)



Meridian

Concentration (μg/L)
2.0
1.5
1.0
0.5
0.0
50
60
70
80
90
100
110
120
130
140
150
Time from injection (hrs)
□ Left Bank
○ Center Line
△ Right Bank
—— Average



Elevation (m)
501
500
499
498
497
496
495
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
Distance from left bank (m)

APPENDIX B

Dye Concentration Data

Sample Site: Fort Saskatchewan @ HWY 15 bridge, 794.2 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Left Bank

Duration = 5.56Hrs
Time to Peak = 16.83Hrs
Background Conc.= 0.024ppb
Peak Conc. = 4.316ppb

Discharge = 129.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 4.059Kg
Recovery Ratio= 1.015

POSITION TIME (Hrs)

Leading edge: 15.98
Cp/2 : 16.42
Peak : 16.83
Centroid : 17.84
Mean : 17.36
Cp/2 : 17.95
Est. End Pt.: 21.53

Half-Duration= 1.53Hrs
Variance = 0.72
Skewness = 1.07
Kurtosis = 0.36
Alpha = 3.25
Beta = 0.00256

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
15.98	0.00	0.000
16.00	0.02	0.073
16.17	0.19	0.598
16.33	0.36	1.393
16.50	0.52	2.885
16.68	0.70	3.928
16.83	0.86	4.316
17.00	1.02	4.133
17.20	1.22	3.757
17.33	1.36	3.311
17.67	1.69	2.660
18.00	2.02	2.078
18.33	2.36	1.735
18.67	2.69	1.417
19.00	3.02	1.237
19.33	3.36	1.068
19.67	3.69	0.913
21.53	5.56	0.000

Sample Site: Fort Saskatchewan @ HWY 15 bridge, 794.2 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Centerline

Duration = 5.64Hrs
Time to Peak = 16.33Hrs
Background Conc.= 0.024ppb
Peak Conc. = 5.812ppb

Discharge = 129.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 4.373Kg
Recovery Ratio= 1.094

POSITION	TIME (Hrs)
Leading edge:	15.50
Cp/2 :	15.93
Peak :	16.33
Centroid :	17.12
Mean :	16.88
Cp/2 :	17.09
Est. End Pt.:	21.14

Half-Duration= 1.16Hrs
Variance = 0.66
Skewness = 1.50
Kurtosis = 1.97
Alpha = 2.05
Beta = 0.00247

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
15.50	0.00	0.000
15.50	0.00	0.020
16.00	0.50	3.396
16.17	0.67	5.377
16.33	0.84	5.812
16.50	1.00	5.304
16.68	1.19	4.305
16.83	1.34	3.668
17.00	1.50	3.106
17.20	1.70	2.660
17.33	1.84	2.181
17.67	2.17	1.838
18.00	2.50	1.359
18.33	2.84	1.085
18.67	3.17	0.842
19.00	3.50	0.778
19.33	3.84	0.656
19.67	4.17	0.536
21.14	5.64	0.000

Sample Site: Fort Saskatchewan @ HWY 15 bridge, 794.2 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Right Bank

Duration = 5.35Hrs
Time to Peak = 16.33Hrs
Background Conc.= 0.024ppb
Peak Conc. = 5.504ppb

Discharge = 129.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 4.112Kg
Recovery Ratio= 1.028

POSITION	TIME (Hrs)
Leading edge:	15.81
Cp/2 :	16.08
Peak :	16.33
Centroid :	17.32
Mean :	16.98
Cp/2 :	17.24
Est. End Pt.:	21.16

Half-Duration= 1.16Hrs
Variance = 0.67
Skewness = 1.41
Kurtosis = 1.58
Alpha = 1.99
Beta = 0.00253

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
15.81	0.00	0.000
16.00	0.19	1.965
16.17	0.36	3.648
16.33	0.53	5.504
16.50	0.69	5.338
16.68	0.87	4.716
16.83	1.03	4.077
17.00	1.19	3.277
17.20	1.39	2.866
17.33	1.53	2.455
17.67	1.86	1.976
18.00	2.19	1.496
18.33	2.53	1.187
18.67	2.86	1.043
19.00	3.19	0.851
19.33	3.53	0.717
19.67	3.86	0.589
21.16	5.35	0.000

```
Sample Site: Fort Saskatchewan @ HWY 15 bridge, 794.2 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Section Average

Duration          =    5.51Hrs        Discharge     = 129.00CMS
Time to Peak      =   16.50Hrs        Dye Injected  =   3.998Kg
Background Conc.=   0.024ppb          Dye Recovered =   4.106Kg
Peak Conc.        =   4.509ppb        Recovery Ratio=   1.027

POSITION    TIME (Hrs)

Leading edge:   15.79          Half-Duration=    1.55Hrs
Cp/2        :   16.05          Variance     =    0.72
Peak        :   16.50          Skewness     =    1.26
Centroid    :   17.44          Kurtosis     =    1.08
Mean        :   17.06          Alpha        =    3.31
Cp/2        :   17.60          Beta         =    0.00266
Est. End Pt.:   21.30

TIME FROM   TIME FROM   CONCENTRATION
INJECTION  LEADING EDGE
  (Hrs)       (Hrs)         (ppb)
  15.79        0.00         0.000
  16.00        0.21         1.811
  16.17        0.38         3.208
  16.33        0.55         4.236
  16.50        0.71         4.509
  16.68        0.90         4.316
  16.83        1.05         4.020
  17.00        1.21         3.505
  17.20        1.41         3.094
  17.33        1.55         2.649
  17.67        1.88         2.158
  18.00        2.21         1.644
  18.33        2.55         1.336
  18.67        2.88         1.101
  19.00        3.21         0.955
  19.33        3.55         0.813
  19.67        3.88         0.679
  21.30        5.51         0.000
```

Sample Site: Vinca Bridge on HWY 38, 764.6 km
Injection @ Cloverdale Footbridge (830.5 km), 01:30, Oct 16, 1990

Location of sample: Left Bank

Duration = 11.50Hrs
Time to Peak = 30.33Hrs
Background Conc.= 0.023ppb
Peak Conc. = 1.000ppb

Discharge = 141.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.157Kg
Recovery Ratio= 0.790

POSITION	TIME (Hrs)
Leading edge:	27.81
Cp/2 :	28.50
Peak :	30.33
Centroid :	32.16
Mean :	31.21
Cp/2 :	34.66
Est. End Pt.:	39.31

Half-Duration= 6.16Hrs
Variance = 4.21
Skewness = 0.80
Kurtosis = 0.06
Alpha = 9.01
Beta = 0.00458

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
27.81	0.00	0.000
28.00	0.19	0.132
28.33	0.52	0.368
28.67	0.85	0.639
29.00	1.18	0.840
29.33	1.52	0.961
29.67	1.85	0.978
30.00	2.19	0.978
30.33	2.52	1.000
30.67	2.85	0.950
31.00	3.19	0.932
31.50	3.69	0.869
32.00	4.18	0.822
32.50	4.69	0.753
33.00	5.19	0.725
33.50	5.68	0.652
34.00	6.19	0.588
35.00	7.18	0.454
36.00	8.19	0.351
37.00	9.19	0.243
39.31	11.50	0.000

Sample Site: Vinca Bridge on HWY 38, 764.6 km
Injection @ Cloverdale Footbridge (830.5 km), 01:30, Oct 16, 1990

Location of sample: Centerline

Duration = 10.70Hrs
Time to Peak = 28.33Hrs
Background Conc.= 0.023ppb
Peak Conc. = 2.042ppb

Discharge = 141.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.395Kg
Recovery Ratio= 0.849

POSITION	TIME (Hrs)
Leading edge:	27.49
Cp/2 :	27.80
Peak :	28.33
Centroid :	30.34
Mean :	29.92
Cp/2 :	30.31
Est. End Pt.:	38.19

Half-Duration= 2.51Hrs
Variance = 3.01
Skewness = 1.30
Kurtosis = 1.64
Alpha = 2.09
Beta = 0.00374

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
27.49	0.00	0.000
27.50	0.01	0.033
28.00	0.51	1.662
28.33	0.85	2.042
28.67	1.18	1.782
29.00	1.51	1.702
29.33	1.84	1.481
29.67	2.18	1.315
30.00	2.51	1.167
30.33	2.84	1.011
30.67	3.18	0.865
31.00	3.51	0.782
31.50	4.01	0.703
32.00	4.51	0.575
32.50	5.01	0.512
33.00	5.51	0.442
33.50	6.01	0.339
34.00	6.51	0.279
35.00	7.51	0.185
36.00	8.51	0.114
37.00	9.51	0.072
38.19	10.70	0.000

Sample Site: Vinca Bridge on HWY 38, 764.6 km
Injection @ Cloverdale Footbridge (830.5 km), 01:30, Oct 16, 1990

Location of sample: Right Bank

Duration = 10.96Hrs
Time to Peak = 28.33Hrs
Background Conc.= 0.023ppb
Peak Conc. = 1.909ppb

Discharge = 141.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.407Kg
Recovery Ratio= 0.852

POSITION	TIME (Hrs)
Leading edge:	27.49
Cp/2 :	27.75
Peak :	28.33
Centroid :	30.33
Mean :	29.89
Cp/2 :	30.51
Est. End Pt.:	38.45

Half-Duration= 2.77Hrs
Variance = 3.04
Skewness = 1.33
Kurtosis = 1.77
Alpha = 2.52
Beta = 0.00378

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
27.49	0.00	0.000
27.50	0.01	0.033
28.00	0.51	1.904
28.33	0.84	1.909
28.67	1.18	1.869
29.00	1.51	1.673
29.33	1.84	1.441
29.67	2.18	1.258
30.00	2.51	1.132
30.33	2.84	1.011
30.67	3.18	0.905
31.00	3.51	0.805
31.50	4.01	0.663
32.00	4.51	0.587
32.50	5.01	0.495
33.00	5.51	0.379
33.50	6.01	0.339
34.00	6.51	0.279
35.00	7.51	0.185
36.00	8.51	0.120
37.00	9.51	0.080
38.45	10.96	0.000

```
Sample Site: Vinca Bridge on HWY 38, 764.6 km
Injection @ Cloverdale Footbridge (830.5 km), 01:30, Oct 16, 1990

Location of sample: Section Average

Duration          =   11.32Hrs        Discharge     = 141.00CMS
Time to Peak      =   28.33Hrs        Dye Injected  =   3.998Kg
Background Conc.=     0.023ppb        Dye Recovered =   3.322Kg
Peak Conc.        =   1.440ppb        Recovery Ratio=   0.831

POSITION     TIME (Hrs)

Leading edge:    27.49          Half-Duration=     3.86Hrs
Cp/2        :    27.79          Variance     =     3.70
Peak        :    28.33          Skewness     =     1.13
Centroid    :    30.90          Kurtosis     =     0.97
Mean        :    30.27          Alpha        =     4.03
Cp/2        :    31.65          Beta         =     0.00461
Est. End Pt.:    38.81

TIME FROM    TIME FROM    CONCENTRATION
INJECTION   LEADING EDGE
  (Hrs)        (Hrs)          (ppb)
  27.49        0.00           0.000
  27.50        0.01           0.033
  28.00        0.52           1.233
  28.33        0.85           1.440
  28.67        1.18           1.430
  29.00        1.51           1.405
  29.33        1.85           1.294
  29.67        2.18           1.184
  30.00        2.51           1.092
  30.33        2.85           1.007
  30.67        3.18           0.907
  31.00        3.52           0.840
  31.50        4.01           0.745
  32.00        4.51           0.662
  32.50        5.02           0.587
  33.00        5.51           0.516
  33.50        6.01           0.443
  34.00        6.52           0.382
  35.00        7.51           0.275
  36.00        8.51           0.195
  37.00        9.52           0.132
  38.81       11.32           0.000
```

Sample Site: Waskatenau @ HWY 831 bridge, 738.9 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Left Bank

Duration = 19.54Hrs
Time to Peak = 39.83Hrs
Background Conc.= 0.018ppb
Peak Conc. = 0.806ppb

Discharge = 155.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 4.234Kg
Recovery Ratio= 1.059

POSITION	TIME (Hrs)
Leading edge:	37.62
Cp/2 :	38.76
Peak :	39.83
Centroid :	44.55
Mean :	41.91
Cp/2 :	47.09
Est. End Pt.:	57.16

Half-Duration= 8.34Hrs
Variance = 6.19
Skewness = 0.52
Kurtosis = -0.84
Alpha = 11.22
Beta = 0.00390

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
37.62	0.00	0.000
37.83	0.21	0.047
38.17	0.55	0.121
38.50	0.88	0.282
38.83	1.21	0.439
39.17	1.54	0.762
39.50	1.88	0.724
39.83	2.21	0.806
40.17	2.54	0.782
40.50	2.88	0.705
41.25	3.63	0.780
41.75	4.13	0.707
42.25	4.63	0.777
42.98	5.36	0.760
43.67	6.04	0.711
44.42	6.80	0.558
45.17	7.54	0.542
45.67	8.05	0.460
46.50	8.88	0.460
47.17	9.55	0.396
57.16	19.54	0.000

```
Sample Site: Waskatenau @ HWY 831 bridge, 738.9 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Centerline

Duration          =    11.53Hrs         Discharge      = 155.00CMS
Time to Peak      =    38.83Hrs         Dye Injected   =    3.998Kg
Background Conc.=      0.018ppb         Dye Recovered  =    4.088Kg
Peak Conc.        =    1.554ppb         Recovery Ratio=     1.022

POSITION     TIME (Hrs)

Leading edge:    37.36            Half-Duration=     4.04Hrs
Cp/2         :   37.92            Variance      =    4.27
Peak         :   38.83            Skewness      =    1.20
Centroid     :   41.01            Kurtosis      =    0.96
Mean         :   40.31            Alpha         =    3.81
Cp/2         :   41.95            Beta          =    0.00283
Est. End Pt.:    48.90

TIME FROM    TIME FROM    CONCENTRATION
INJECTION   LEADING EDGE
  (Hrs)        (Hrs)          (ppb)
  37.36         0.00          0.000
  37.50         0.14          0.189
  37.83         0.47          0.652
  38.17         0.80          1.162
  38.50         1.14          1.505
  38.83         1.47          1.554
  39.17         1.80          1.517
  39.50         2.14          1.442
  39.83         2.47          1.322
  40.17         2.80          1.263
  40.50         3.14          1.135
  41.25         3.89          0.958
  41.75         4.39          0.813
  42.25         4.89          0.724
  42.98         5.62          0.647
  43.67         6.30          0.511
  44.42         7.05          0.387
  45.17         7.80          0.310
  45.67         8.30          0.236
  46.50         9.14          0.164
  47.17         9.80          0.129
  48.90        11.53          0.000
```

```
Sample Site: Waskatenau @ HWY 831 bridge, 738.9 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Right Bank

Duration         =   13.43Hrs         Discharge      = 155.00CMS
Time to Peak     =   40.50Hrs         Dye Injected  =    3.998Kg
Background Conc.=   0.018ppb         Dye Recovered =    3.965Kg
Peak Conc.       =   0.853ppb         Recovery Ratio=    0.992

POSITION    TIME (Hrs)

Leading edge:   37.43          Half-Duration=    8.10Hrs
Cp/2        :   38.24          Variance     =    6.33
Peak        :   40.50          Skewness     =    0.53
Centroid    :   42.80          Kurtosis     =   -0.79
Mean        :   41.61          Alpha        =   10.35
Cp/2        :   46.34          Beta         =    0.00386
Est. End Pt.:   50.86

TIME FROM   TIME FROM    CONCENTRATION
INJECTION  LEADING EDGE
  (Hrs)        (Hrs)          (ppb)
  37.43         0.00          0.000
  37.50         0.07          0.027
  37.83         0.40          0.154
  38.17         0.74          0.378
  38.50         1.07          0.604
  38.83         1.41          0.783
  39.17         1.74          0.848
  39.50         2.07          0.744
  39.83         2.40          0.786
  40.17         2.74          0.815
  40.50         3.07          0.853
  41.25         3.82          0.852
  41.75         4.32          0.826
  42.25         4.82          0.844
  42.98         5.55          0.819
  43.67         6.24          0.777
  44.42         6.99          0.690
  45.17         7.74          0.608
  45.67         8.24          0.506
  46.50         9.07          0.407
  47.17         9.74          0.363
  50.86        13.43          0.000
```

Sample Site: Waskatenau @ HWY 831 bridge, 738.9 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Section Average

Duration = 14.02Hrs
Time to Peak = 39.17Hrs
Background Conc.= 0.018ppb
Peak Conc. = 1.042ppb

Discharge = 155.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.933Kg
Recovery Ratio= 0.984

POSITION	TIME (Hrs)
Leading edge:	37.39
Cp/2 :	38.13
Peak :	39.17
Centroid :	42.40
Mean :	41.15
Cp/2 :	44.73
Est. End Pt.:	51.41

Half-Duration= 6.60Hrs
Variance = 5.96
Skewness = 0.77
Kurtosis = -0.38
Alpha = 7.31
Beta = 0.00388

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
37.39	0.00	0.000
37.50	0.11	0.072
37.83	0.45	0.284
38.17	0.78	0.554
38.50	1.11	0.797
38.83	1.45	0.925
39.17	1.78	1.042
39.50	2.11	0.970
39.83	2.45	0.971
40.17	2.78	0.953
40.50	3.11	0.898
41.25	3.86	0.863
41.75	4.36	0.782
42.25	4.86	0.782
42.98	5.60	0.742
43.67	6.28	0.667
44.42	7.03	0.545
45.17	7.78	0.487
45.67	8.28	0.401
46.50	9.11	0.344
47.17	9.78	0.296
51.41	14.02	0.000

Sample Site: Pakan Ferry, 710.9 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Left Bank

Duration = 19.95Hrs
Time to Peak = 50.00Hrs
Background Conc.= 0.028ppb
Peak Conc. = 0.741ppb

Discharge = 173.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.809Kg
Recovery Ratio= 0.953

POSITION TIME (Hrs)

Leading edge: 46.67
Cp/2 : 48.45
Peak : 50.00
Centroid : 53.49
Mean : 52.59
Cp/2 : 56.08
Est. End Pt.: 66.62

Half-Duration= 7.63Hrs
Variance = 11.46
Skewness = 1.11
Kurtosis = 0.56
Alpha = 5.08
Beta = 0.00458

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
46.67	0.00	0.000
48.50	1.83	0.380
49.00	2.33	0.484
49.50	2.83	0.693
50.00	3.33	0.741
50.50	3.83	0.714
51.00	4.33	0.651
51.50	4.83	0.678
52.00	5.33	0.658
53.00	6.33	0.593
54.00	7.33	0.507
55.00	8.33	0.444
56.00	9.33	0.377
57.00	10.33	0.297
58.00	11.33	0.246
59.00	12.33	0.182
60.00	13.33	0.143
61.00	14.33	0.124
62.00	15.33	0.101
63.00	16.33	0.080
66.62	19.95	0.000

Sample Site: Pakan Ferry, 710.9 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Centerline

Duration = 18.11Hrs
Time to Peak = 50.50Hrs
Background Conc.= 0.028ppb
Peak Conc. = 0.760ppb

Discharge = 173.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.664Kg
Recovery Ratio= 0.917

POSITION TIME (Hrs)

Leading edge: 47.86
Cp/2 : 48.59
Peak : 50.50
Centroid : 53.55
Mean : 52.49
Cp/2 : 55.86
Est. End Pt.: 65.97

Half-Duration= 7.27Hrs
Variance = 11.14
Skewness = 1.15
Kurtosis = 0.67
Alpha = 4.74
Beta = 0.00437

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
47.86	0.00	0.000
48.50	0.64	0.332
49.00	1.14	0.594
49.50	1.64	0.740
50.00	2.14	0.759
50.50	2.64	0.760
51.00	3.14	0.651
51.50	3.64	0.689
52.00	4.14	0.652
53.00	5.14	0.587
54.00	6.14	0.513
55.00	7.14	0.440
56.00	8.14	0.370
57.00	9.14	0.282
58.00	10.14	0.236
59.00	11.14	0.185
60.00	12.14	0.139
61.00	13.14	0.120
62.00	14.14	0.094
63.00	15.14	0.072
65.97	18.11	0.000

Sample Site: Pakan Ferry, 710.9 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Right Bank

Duration = 19.39Hrs
Time to Peak = 50.50Hrs
Background Conc.= 0.028ppb
Peak Conc. = 0.680ppb

Discharge = 173.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.725Kg
Recovery Ratio= 0.932

POSITION TIME (Hrs)

Leading edge: 47.98
Cp/2 : 48.85
Peak : 50.50
Centroid : 54.26
Mean : 53.01
Cp/2 : 56.89
Est. End Pt.: 67.37

Half-Duration= 8.04Hrs
Variance = 12.27
Skewness = 0.99
Kurtosis = 0.17
Alpha = 5.27
Beta = 0.00481

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
47.98	0.00	0.000
48.50	0.51	0.203
49.00	1.02	0.401
49.50	1.52	0.583
50.00	2.01	0.660
50.50	2.52	0.680
51.00	3.02	0.668
51.50	3.51	0.666
52.00	4.02	0.647
53.00	5.01	0.604
54.00	6.02	0.530
55.00	7.02	0.472
56.00	8.01	0.418
57.00	9.02	0.330
58.00	10.02	0.279
59.00	11.01	0.221
60.00	12.02	0.173
61.00	13.02	0.145
62.00	14.01	0.127
63.00	15.02	0.099
67.37	19.39	0.000

Sample Site: Pakan Ferry, 710.9 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Section Average

Duration = 19.05Hrs
Time to Peak = 50.00Hrs
Background Conc. = 0.028ppb
Peak Conc. = 0.720ppb

Discharge = 173.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.706Kg
Recovery Ratio = 0.927

POSITION TIME (Hrs)

Leading edge: 47.69
Cp/2 : 48.65
Peak : 50.00
Centroid : 53.81
Mean : 52.69
Cp/2 : 56.33
Est. End Pt.: 66.74

Half-Duration = 7.68Hrs
Variance = 11.66
Skewness = 1.08
Kurtosis = 0.46
Alpha = 5.06
Beta = 0.00467

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
47.69	0.00	0.000
48.50	0.81	0.305
49.00	1.32	0.493
49.50	1.81	0.672
50.00	2.31	0.720
50.50	2.82	0.718
51.00	3.31	0.657
51.50	3.81	0.678
52.00	4.32	0.652
53.00	5.31	0.595
54.00	6.31	0.517
55.00	7.32	0.452
56.00	8.31	0.388
57.00	9.31	0.303
58.00	10.32	0.254
59.00	11.31	0.196
60.00	12.31	0.152
61.00	13.32	0.129
62.00	14.31	0.107
63.00	15.31	0.084
66.74	19.05	0.000

Sample Site: Shandro Bridge on HWY 857, 683.7 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Left Bank

Duration = 23.11Hrs
Time to Peak = 64.50Hrs
Background Conc. = 0.035ppb
Peak Conc. = 0.627ppb

Discharge = 163.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.972Kg
Recovery Ratio = 0.994

POSITION TIME (Hrs)

Leading edge: 59.31
Cp/2 : 60.93
Peak : 64.50
Centroid : 67.43
Mean : 65.91
Cp/2 : 71.13
Est. End Pt.: 82.42

Half-Duration = 10.19Hrs
Variance = 15.57
Skewness = 0.93
Kurtosis = 0.32
Alpha = 6.67
Beta = 0.00374

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
59.31	0.00	0.000
59.50	0.19	0.036
60.00	0.69	0.129
60.50	1.19	0.209
61.00	1.69	0.330
61.50	2.19	0.424
62.00	2.69	0.492
62.50	3.19	0.544
63.00	3.69	0.574
63.50	4.19	0.598
64.00	4.69	0.614
64.50	5.19	0.627
65.00	5.69	0.600
65.50	6.19	0.607
66.00	6.69	0.600
66.50	7.19	0.568
67.50	8.19	0.496
68.50	9.19	0.453
69.50	10.19	0.401
70.50	11.19	0.346
71.50	12.19	0.294
72.50	13.19	0.262
73.50	14.19	0.202
74.50	15.19	0.156
75.50	16.19	0.138
76.50	17.19	0.119
77.50	18.19	0.098
82.42	23.11	0.000

Sample Site: Shandro Bridge on HWY 857, 683.7 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Centerline

Duration = 21.02Hrs
Time to Peak = 62.00Hrs
Background Conc.= 0.035ppb
Peak Conc. = 0.648ppb

Discharge = 163.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.844Kg
Recovery Ratio= 0.961

POSITION TIME (Hrs)

Leading edge: 58.74
Cp/2 : 59.92
Peak : 62.00
Centroid : 65.99
Mean : 64.85
Cp/2 : 69.38
Est. End Pt.: 79.76

Half-Duration= 9.46Hrs
Variance = 14.29
Skewness = 1.03
Kurtosis = 0.77
Alpha = 6.26
Beta = 0.00372

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
58.74	0.00	0.000
59.00	0.26	0.069
59.50	0.76	0.202
60.00	1.26	0.348
60.50	1.76	0.455
61.00	2.26	0.544
61.50	2.76	0.608
62.00	3.26	0.648
62.50	3.76	0.618
63.00	4.26	0.635
63.50	4.76	0.631
64.00	5.26	0.621
64.50	5.76	0.601
65.00	6.26	0.587
65.50	6.76	0.555
66.00	7.26	0.529
66.50	7.76	0.503
67.50	8.76	0.438
68.50	9.76	0.381
69.50	10.76	0.316
70.50	11.76	0.307
71.50	12.76	0.236
72.50	13.76	0.171
73.50	14.76	0.150
74.50	15.76	0.111
75.50	16.76	0.093
76.50	17.76	0.073
77.50	18.76	0.049
79.76	21.02	0.000

```
Sample Site: Shandro Bridge on HWY 857, 683.7 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Right Bank

Duration          =   22.33Hrs         Discharge      = 163.00CMS
Time to Peak      =   63.00Hrs         Dye Injected   =   3.998Kg
Background Conc.=     0.035ppb         Dye Recovered =    3.865Kg
Peak Conc.        =   0.641ppb         Recovery Ratio=    0.976

POSITION    TIME (Hrs)

Leading edge:    58.72          Half-Duration=     9.81Hrs
Cp/2        :    59.95          Variance      =   14.36
Peak        :    63.00          Skewness      =    1.04
Centroid    :    66.16          Kurtosis      =    0.83
Mean        :    64.92          Alpha         =    6.70
Cp/2        :    69.77          Beta          =    0.00362
Est. End Pt.:    81.05

TIME FROM   TIME FROM   CONCENTRATION
INJECTION  LEADING EDGE
  (Hrs)        (Hrs)        (ppb)
  58.72         0.00        0.000
  59.00         0.28        0.062
  59.50         0.78        0.175
  60.00         1.28        0.335
  60.50         1.78        0.428
  61.00         2.28        0.517
  61.50         2.78        0.587
  62.00         3.28        0.628
  62.50         3.78        0.638
  63.00         4.28        0.641
  63.50         4.78        0.638
  64.00         5.28        0.621
  64.50         5.78        0.614
  65.00         6.28        0.587
  65.50         6.78        0.555
  66.00         7.28        0.535
  66.50         7.78        0.503
  67.50         8.78        0.457
  68.50         9.78        0.388
  69.50        10.78        0.335
  70.50        11.78        0.281
  71.50        12.78        0.229
  72.50        13.78        0.177
  73.50        14.78        0.144
  74.50        15.78        0.117
  75.50        16.78        0.093
  76.50        17.78        0.080
  77.50        18.78        0.059
  81.05        22.33        0.000
```

```
Sample Site: Shandro Bridge on HWY 857, 683.7 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Section Average

Duration          =   22.29Hrs        Discharge      = 163.00CMS
Time to Peak      =   63.50Hrs        Dye Injected  =    3.998Kg
Background Conc.=   0.035ppb        Dye Recovered =    3.888Kg
Peak Conc.        =   0.622ppb        Recovery Ratio=    0.973

POSITION    TIME (Hrs)

Leading edge:   58.79          Half-Duration=   10.30Hrs
Cp/2        :   60.21          Variance     =   14.96
Peak        :   63.50          Skewness     =    0.99
Centroid    :   66.51          Kurtosis     =    0.62
Mean        :   65.22          Alpha        =    7.10
Cp/2        :   70.52          Beta         =    0.00371
Est. End Pt.:   81.08

TIME FROM   TIME FROM   CONCENTRATION
INJECTION  LEADING EDGE
  (Hrs)       (Hrs)          (ppb)
  58.79        0.00          0.000
  59.00        0.20          0.040
  59.50        0.71          0.138
  60.00        1.21          0.271
  60.50        1.70          0.364
  61.00        2.21          0.464
  61.50        2.71          0.540
  62.00        3.20          0.590
  62.50        3.71          0.600
  63.00        4.21          0.617
  63.50        4.70          0.622
  64.00        5.21          0.619
  64.50        5.71          0.614
  65.00        6.20          0.591
  65.50        6.71          0.572
  66.00        7.21          0.555
  66.50        7.70          0.524
  67.50        8.71          0.464
  68.50        9.71          0.407
  69.50       10.70          0.351
  70.50       11.71          0.312
  71.50       12.71          0.253
  72.50       13.70          0.203
  73.50       14.71          0.165
  74.50       15.71          0.128
  75.50       16.70          0.108
  76.50       17.71          0.091
  77.50       18.71          0.069
  81.08       22.29          0.000
```

```
Sample Site: Duvernay d/s of HWY 36 bridge, 633.4 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Left Bank

Duration          =   27.56Hrs        Discharge      = 169.00CMS
Time to Peak      =   88.50Hrs        Dye Injected   =    3.998Kg
Background Conc.=     0.023ppb        Dye Recovered =     3.758Kg
Peak Conc.        =   0.460ppb        Recovery Ratio=     0.940

POSITION     TIME (Hrs)

Leading edge:    80.13           Half-Duration=    12.89Hrs
Cp/2         :   82.74           Variance      =   23.11
Peak         :   88.50           Skewness      =    0.95
Centroid     :   90.35           Kurtosis      =    0.73
Mean         :   88.70           Alpha         =    7.19
Cp/2         :   95.63           Beta          =    0.00295
Est. End Pt.:   107.69

TIME FROM    TIME FROM    CONCENTRATION
INJECTION   LEADING EDGE
  (Hrs)        (Hrs)          (ppb)
  80.13         0.00          0.000
  80.50         0.37          0.033
  81.50         1.37          0.121
  82.50         2.37          0.214
  83.50         3.37          0.281
  84.50         4.37          0.356
  85.50         5.37          0.413
  86.50         6.37          0.454
  87.50         7.37          0.437
  88.50         8.37          0.460
  89.50         9.37          0.452
  91.50        11.37          0.409
  93.50        13.37          0.322
  96.00        15.87          0.214
  97.50        17.37          0.154
 100.50        20.37          0.084
 102.50        22.37          0.057
 104.50        24.37          0.038
 107.69        27.56          0.000
```

```
Sample Site: Duvernay d/s of HWY 36 bridge, 633.4 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Centerline

Duration          =   27.40Hrs        Discharge      = 169.00CMS
Time to Peak      =   86.50Hrs        Dye Injected   =    3.998Kg
Background Conc.=     0.023ppb        Dye Recovered =     3.791Kg
Peak Conc.        =   0.468ppb        Recovery Ratio=     0.948

POSITION    TIME (Hrs)

Leading edge:   80.02           Half-Duration=   12.94Hrs
Cp/2        :   82.42           Variance     =   22.55
Peak        :   86.50           Skewness     =    0.98
Centroid    :   90.08           Kurtosis     =    0.83
Mean        :   88.46           Alpha        =    7.43
Cp/2        :   95.37           Beta         =    0.00301
Est. End Pt.:  107.42

TIME FROM   TIME FROM   CONCENTRATION
INJECTION  LEADING EDGE
  (Hrs)       (Hrs)         (ppb)
  80.02        0.00         0.000
  80.50        0.48         0.040
  81.50        1.48         0.123
  82.50        2.48         0.243
  83.50        3.48         0.319
  84.50        4.48         0.390
  85.50        5.48         0.442
  86.50        6.48         0.468
  87.50        7.48         0.466
  88.50        8.48         0.466
  89.50        9.48         0.435
  91.50       11.48         0.394
  93.50       13.48         0.308
  96.00       15.98         0.209
  97.50       17.48         0.154
 100.50       20.48         0.079
 102.50       22.48         0.053
 104.50       24.48         0.034
 107.42       27.40         0.000
```

```
Sample Site: Duvernay d/s of HWY 36 bridge, 633.4 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Right Bank

Duration          =   27.51Hrs        Discharge      = 169.00CMS
Time to Peak      =   87.50Hrs        Dye Injected   =    3.998Kg
Background Conc.=     0.023ppb        Dye Recovered =     3.769Kg
Peak Conc.        =   0.455ppb        Recovery Ratio=     0.943

POSITION     TIME (Hrs)

Leading edge:     80.22          Half-Duration=    12.93Hrs
Cp/2          :   83.08          Variance      =   23.69
Peak          :   87.50          Skewness      =    0.94
Centroid      :   90.69          Kurtosis      =    0.60
Mean          :   89.01          Alpha         =    7.06
Cp/2          :   96.01          Beta          =    0.00309
Est. End Pt.:    107.73

TIME FROM    TIME FROM    CONCENTRATION
INJECTION   LEADING EDGE
  (Hrs)        (Hrs)          (ppb)
  80.22         0.00          0.000
  80.50         0.28          0.019
  81.50         1.28          0.086
  82.50         2.28          0.172
  83.50         3.28          0.267
  84.50         4.28          0.347
  85.50         5.28          0.409
  86.50         6.28          0.444
  87.50         7.28          0.455
  88.50         8.28          0.448
  89.50         9.28          0.435
  91.50        11.28          0.404
  93.50        13.28          0.346
  96.00        15.78          0.228
  97.50        17.28          0.172
 100.50        20.28          0.093
 102.50        22.28          0.065
 104.50        24.28          0.042
 107.73        27.51          0.000
```

```
Sample Site: Duvernay d/s of HWY 36 bridge, 633.4 km
Injection @ Cloverdale Footbridge (830.5 km) @ 01:30, Oct 16, 1990

Location of sample: Section Average

Duration         =   27.56Hrs         Discharge     = 169.00CMS
Time to Peak     =   88.50Hrs         Dye Injected  =   3.998Kg
Background Conc.=    0.023ppb         Dye Recovered =   3.773Kg
Peak Conc.       =   0.458ppb         Recovery Ratio=   0.944

POSITION    TIME (Hrs)

Leading edge:   80.11           Half-Duration=   12.98Hrs
Cp/2        :   82.74           Variance     =   23.18
Peak        :   88.50           Skewness     =    0.96
Centroid    :   90.37           Kurtosis     =    0.72
Mean        :   88.72           Alpha        =    7.27
Cp/2        :   95.72           Beta         =    0.00296
Est. End Pt.:  107.66

TIME FROM   TIME FROM   CONCENTRATION
INJECTION  LEADING EDGE
  (Hrs)        (Hrs)         (ppb)
  80.11         0.00         0.000
  80.50         0.39         0.031
  81.50         1.39         0.110
  82.50         2.39         0.210
  83.50         3.39         0.289
  84.50         4.39         0.364
  85.50         5.39         0.421
  86.50         6.39         0.455
  87.50         7.39         0.453
  88.50         8.39         0.458
  89.50         9.39         0.441
  91.50        11.39         0.402
  93.50        13.39         0.325
  96.00        15.89         0.217
  97.50        17.39         0.160
 100.50        20.39         0.085
 102.50        22.39         0.059
 104.50        24.39         0.038
 107.66        27.56         0.000
```

Sample Site: Duvernay, d/s of HWY 36 bridge, 633.4 km
Injection @ Shandro Bridge (683.8 km) @ 15:00, Oct 8, 1990

Location of sample: Left Bank

Duration = 7.30Hrs
Time to Peak = 22.33Hrs
Background Conc.= 0.026ppb
Peak Conc. = 3.089ppb

Discharge = 137.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 4.406Kg
Recovery Ratio= 1.102

POSITION TIME (Hrs)

Leading edge: 21.43
Cp/2 : 21.74
Peak : 22.33
Centroid : 23.76
Mean : 22.98
Cp/2 : 24.08
Est. End Pt.: 28.73

Half-Duration= 2.34Hrs
Variance = 1.15
Skewness = 1.31
Kurtosis = 1.74
Alpha = 4.76
Beta = 0.00231

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
21.43	0.00	0.000
21.50	0.07	0.352
21.67	0.24	1.232
21.83	0.40	1.956
22.00	0.57	2.392
22.17	0.73	3.029
22.33	0.90	3.089
22.50	1.07	3.058
22.67	1.23	2.859
22.83	1.40	2.783
23.00	1.57	2.540
23.33	1.90	2.100
23.67	2.23	1.921
24.00	2.57	1.604
24.33	2.90	1.364
24.75	3.32	1.178
25.00	3.57	1.076
25.50	4.07	0.875
27.00	5.57	0.496
28.73	7.30	0.000

Sample Site: Duvernay, d/s of HWY 36 bridge, 633.4 km
Injection @ Shandro Bridge (683.8 km) @ 15:00, Oct 8, 1990

Location of sample: Centerline

Duration = 6.61Hrs
Time to Peak = 22.33Hrs
Background Conc.= 0.026ppb
Peak Conc. = 4.509ppb

Discharge = 137.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 4.018Kg
Recovery Ratio= 1.005

POSITION	TIME (Hrs)
Leading edge:	21.46
Cp/2 :	21.83
Peak :	22.33
Centroid :	23.17
Mean :	22.71
Cp/2 :	23.15
Est. End Pt.:	28.07

Half-Duration= 1.32Hrs
Variance = 0.74
Skewness = 1.75
Kurtosis = 3.99
Alpha = 2.36
Beta = 0.00148

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
21.46	0.00	0.000
21.50	0.04	0.273
21.67	0.21	1.466
21.83	0.37	2.247
22.00	0.54	3.503
22.17	0.71	4.306
22.33	0.87	4.509
22.50	1.04	4.235
22.67	1.20	3.596
22.83	1.37	3.231
23.00	1.54	2.688
23.33	1.87	1.749
23.67	2.21	1.372
24.00	2.54	1.118
24.33	2.87	0.922
24.75	3.29	0.690
25.00	3.54	0.590
25.50	4.04	0.460
27.00	5.54	0.205
28.07	6.61	0.000

Sample Site: Duvernay, d/s of HWY 36 bridge, 633.4 km
Injection @ Shandro Bridge (683.8 km) @ 15:00, Oct 8, 1990

Location of sample: Right Bank

Duration = 6.44Hrs
Time to Peak = 22.67Hrs
Background Conc.= 0.026ppb
Peak Conc. = 3.780ppb

Discharge = 137.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.796Kg
Recovery Ratio= 0.949

POSITION	TIME (Hrs)
Leading edge:	21.56
Cp/2 :	22.12
Peak :	22.67
Centroid :	23.53
Mean :	23.03
Cp/2 :	23.69
Est. End Pt.:	28.00

Half-Duration= 1.58Hrs
Variance = 0.77
Skewness = 1.53
Kurtosis = 2.90
Alpha = 3.22
Beta = 0.00150

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
21.56	0.00	0.000
21.67	0.11	0.176
21.83	0.27	0.449
22.00	0.44	0.997
22.17	0.61	2.278
22.33	0.77	3.164
22.50	0.94	3.636
22.67	1.11	3.780
22.83	1.27	3.687
23.00	1.44	3.355
23.33	1.77	2.479
23.67	2.11	1.921
24.00	2.44	1.531
24.33	2.77	1.139
24.75	3.19	0.848
25.00	3.44	0.722
25.50	3.94	0.577
27.00	5.44	0.241
28.00	6.44	0.000

```
Sample Site: Duvernay, d/s of HWY 36 bridge, 633.4 km
Injection @ Shandro Bridge (683.8 km) @ 15:00, Oct 8, 1990

Location of sample: Section Average

Duration         =    6.86Hrs        Discharge     = 137.00CMS
Time to Peak     =   22.50Hrs        Dye Injected  =   3.998Kg
Background Conc.=   0.026ppb        Dye Recovered =   4.067Kg
Peak Conc.       =   3.643ppb        Recovery Ratio=   1.017

POSITION    TIME (Hrs)

Leading edge:   21.45          Half-Duration=    1.70Hrs
Cp/2        :   21.89          Variance     =    0.91
Peak        :   22.50          Skewness     =    1.50
Centroid    :   23.49          Kurtosis     =    2.70
Mean        :   22.90          Alpha        =    3.18
Cp/2        :   23.59          Beta         =    0.00179
Est. End Pt.:   28.31

TIME FROM   TIME FROM   CONCENTRATION
INJECTION  LEADING EDGE
  (Hrs)       (Hrs)         (ppb)
  21.45        0.00         0.000
  21.50        0.05         0.211
  21.67        0.22         0.958
  21.83        0.38         1.550
  22.00        0.55         2.297
  22.17        0.71         3.204
  22.33        0.88         3.587
  22.50        1.05         3.643
  22.67        1.21         3.411
  22.83        1.38         3.234
  23.00        1.55         2.861
  23.33        1.88         2.109
  23.67        2.21         1.738
  24.00        2.55         1.418
  24.33        2.88         1.142
  24.75        3.30         0.905
  25.00        3.55         0.796
  25.50        4.05         0.637
  27.00        5.55         0.314
  28.31        6.86         0.000
```

Sample Site: Myrnam, d/s of HWY 881 bridge, 599.2 km
Injection @ Shandro Bridge (683.8 km) @ 15:00, Oct 8, 1990

Location of sample: Left Bank

Duration = 13.94Hrs
Time to Peak = 40.25Hrs
Background Conc.= 0.025ppb
Peak Conc. = 1.270ppb

Discharge = 114.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.512Kg
Recovery Ratio= 0.878

POSITION TIME (Hrs)

Leading edge: 37.34
Cp/2 : 38.64
Peak : 40.25
Centroid : 42.72
Mean : 41.20
Cp/2 : 44.75
Est. End Pt.: 51.29

Half-Duration= 6.10Hrs
Variance = 5.82
Skewness = 1.17
Kurtosis = 0.55
Alpha = 6.40
Beta = 0.00359

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
37.34	0.00	0.000
37.50	0.16	0.051
37.75	0.41	0.131
38.25	0.91	0.405
38.75	1.41	0.699
39.00	1.66	0.824
39.25	1.91	1.075
39.50	2.16	1.044
39.75	2.41	1.207
40.00	2.66	1.232
40.25	2.91	1.270
40.75	3.41	1.232
41.25	3.91	1.182
42.00	4.66	1.058
43.00	5.66	0.923
44.00	6.66	0.726
45.00	7.66	0.604
46.00	8.66	0.533
47.00	9.66	0.435
48.00	10.66	0.331
51.29	13.94	0.000

Sample Site: Myrnam, d/s of HWY 881 bridge, 599.2 km
Injection @ Shandro Bridge (683.8 km) @ 15:00, Oct 8, 1990

Location of sample: Centerline

Duration = 15.08Hrs
Time to Peak = 40.00Hrs
Background Conc.= 0.025ppb
Peak Conc. = 1.320ppb

Discharge = 114.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.515Kg
Recovery Ratio= 0.879

POSITION TIME (Hrs)

Leading edge: 36.93
Cp/2 : 38.40
Peak : 40.00
Centroid : 42.46
Mean : 40.89
Cp/2 : 44.21
Est. End Pt.: 52.00

Half-Duration= 5.81Hrs
Variance = 5.41
Skewness = 1.33
Kurtosis = 1.13
Alpha = 6.24
Beta = 0.00338

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
36.93	0.00	0.000
37.00	0.07	0.012
37.50	0.57	0.093
37.75	0.82	0.253
38.25	1.32	0.525
38.75	1.82	0.978
39.00	2.07	1.082
39.25	2.32	1.232
39.50	2.57	1.295
39.75	2.82	1.314
40.00	3.07	1.320
40.25	3.32	1.308
40.75	3.82	1.226
41.25	4.32	1.126
42.00	5.07	0.971
43.00	6.07	0.803
44.00	7.07	0.688
45.00	8.07	0.554
46.00	9.07	0.437
47.00	10.07	0.377
48.00	11.07	0.290
52.00	15.08	0.000

Sample Site: Myrnam, d/s of HWY 881 bridge, 599.2 km
Injection @ Shandro Bridge (683.8 km) @ 15:00, Oct 8, 1990

Location of sample: Right Bank

Duration = 13.65Hrs
Time to Peak = 40.00Hrs
Background Conc.= 0.025ppb
Peak Conc. = 1.239ppb

Discharge = 114.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.306Kg
Recovery Ratio= 0.827

POSITION TIME (Hrs)

Leading edge: 37.32
Cp/2 : 38.81
Peak : 40.00
Centroid : 42.73
Mean : 41.23
Cp/2 : 44.77
Est. End Pt.: 50.97

Half-Duration= 5.97Hrs
Variance = 5.85
Skewness = 1.16
Kurtosis = 0.50
Alpha = 6.09
Beta = 0.00365

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
37.32	0.00	0.000
37.50	0.18	0.053
37.75	0.43	0.125
38.25	0.93	0.311
38.75	1.43	0.566
39.00	1.68	0.793
39.25	1.93	0.956
39.50	2.18	1.082
39.75	2.43	1.182
40.00	2.68	1.239
40.25	2.93	1.214
40.75	3.43	1.176
41.25	3.93	1.082
42.00	4.68	0.990
43.00	5.68	0.828
44.00	6.68	0.738
45.00	7.68	0.585
46.00	8.68	0.533
47.00	9.68	0.409
48.00	10.68	0.321
50.97	13.65	0.000

```
Sample Site: Myrnam, d/s of HWY 881 bridge, 599.2 km
Injection @ Shandro Bridge (683.8 km) @ 15:00, Oct 8, 1990

Location of sample: Section Average

Duration           =   14.46Hrs         Discharge     = 114.00CMS
Time to Peak       =   40.00Hrs         Dye Injected  =    3.998Kg
Background Conc.=      0.025ppb         Dye Recovered =    3.444Kg
Peak Conc.         =   1.264ppb         Recovery Ratio=    0.861

POSITION     TIME (Hrs)

Leading edge:    36.89            Half-Duration=     6.05Hrs
Cp/2        :    38.58            Variance     =     5.71
Peak        :    40.00            Skewness     =     1.22
Centroid    :    42.62            Kurtosis     =     0.71
Mean        :    41.10            Alpha        =     6.40
Cp/2        :    44.63            Beta         =     0.00357
Est. End Pt.:    51.35

TIME FROM    TIME FROM    CONCENTRATION
INJECTION   LEADING EDGE
  (Hrs)        (Hrs)          (ppb)
  36.89         0.00          0.000
  37.00         0.11          0.012
  37.50         0.61          0.066
  37.75         0.86          0.170
  38.25         1.36          0.413
  38.75         1.86          0.748
  39.00         2.11          0.899
  39.25         2.36          1.088
  39.50         2.61          1.140
  39.75         2.86          1.235
  40.00         3.11          1.264
  40.25         3.36          1.264
  40.75         3.86          1.211
  41.25         4.36          1.130
  42.00         5.11          1.006
  43.00         6.11          0.851
  44.00         7.11          0.718
  45.00         8.11          0.581
  46.00         9.11          0.501
  47.00        10.11          0.407
  48.00        11.11          0.314
  51.35        14.46          0.000
```

```
Sample Site: Elk Point Bridge on HWY 41, 574.0 km
Injection @ Shandro Bridge (638.8 km) @ 15:00, Oct 08, 1990

Location of sample: Left Bank

Duration          =   18.46Hrs        Discharge      = 108.00CMS
Time to Peak      =   55.33Hrs        Dye Injected   =   3.998Kg
Background Conc.=     0.025ppb        Dye Recovered =    3.893Kg
Peak Conc.        =   1.035ppb        Recovery Ratio=    0.974

POSITION     TIME (Hrs)

Leading edge:    50.58            Half-Duration=     9.37Hrs
Cp/2         :   53.26            Variance       =  10.41
Peak         :   55.33            Skewness       =   0.77
Centroid     :   58.65            Kurtosis       =  -0.16
Mean         :   57.03            Alpha          =   8.44
Cp/2         :   62.63            Beta           =   0.00340
Est. End Pt.:    69.04

TIME FROM    TIME FROM    CONCENTRATION
INJECTION   LEADING EDGE
  (Hrs)         (Hrs)          (ppb)
  50.58          0.00          0.000
  51.50          0.92          0.055
  52.00          1.42          0.085
  52.33          1.75          0.202
  52.67          2.09          0.293
  53.00          2.42          0.423
  53.33          2.75          0.544
  53.67          3.09          0.677
  54.00          3.42          0.860
  54.33          3.75          0.839
  54.67          4.09          0.867
  55.00          4.42          0.991
  55.33          4.75          1.035
  55.67          5.09          1.034
  56.00          5.42          1.026
  57.00          6.42          1.005
  57.67          7.09          0.991
  58.33          7.75          0.960
  59.13          8.55          0.851
  59.67          9.09          0.817
  60.25          9.67          0.771
  61.25         10.67          0.662
  62.58         12.00          0.521
  63.58         13.00          0.451
  64.50         13.92          0.369
  65.50         14.92          0.293
  69.04         18.46          0.000
```

Sample Site: Elk Point Bridge on HWY 41, 574.0 km
Injection @ Shandro Bridge (638.8 km) @ 15:00, Oct 08, 1990

Location of sample: Centerline

Duration	= 17.69Hrs	Discharge	= 108.00CMS
Time to Peak	= 54.33Hrs	Dye Injected	= 3.998Kg
Background Conc.	= 0.025ppb	Dye Recovered	= 4.020Kg
Peak Conc.	= 1.325ppb	Recovery Ratio	= 1.006

POSITION	TIME (Hrs)		
Leading edge	50.44	Half-Duration	7.10Hrs
Cp/2	51.96	Variance	8.59
Peak	54.33	Skewness	1.17
Centroid	56.83	Kurtosis	1.08
Mean	55.54	Alpha	5.87
Cp/2	59.06	Beta	0.00291
Est. End Pt.	68.13		

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
50.44	0.00	0.000
50.50	0.06	0.013
51.00	0.56	0.123
51.50	1.06	0.386
52.00	1.56	0.687
52.33	1.89	0.844
52.67	2.22	0.983
53.00	2.56	1.127
53.33	2.89	1.171
53.67	3.22	1.247
54.00	3.56	1.296
54.33	3.89	1.325
54.67	4.23	1.276
55.00	4.56	1.317
55.33	4.89	1.200
55.67	5.22	1.154
56.00	5.56	1.082
57.00	6.56	0.957
57.67	7.23	0.835
58.33	7.89	0.806
59.13	8.69	0.648
59.67	9.22	0.581
60.25	9.81	0.546
61.25	10.81	0.445
62.58	12.14	0.334
63.58	13.14	0.258
64.50	14.06	0.208
65.50	15.06	0.149
68.13	17.69	0.000

Sample Site: Elk Point Bridge on HWY 41, 574.0 km
Injection @ Shandro Bridge (638.8 km) @ 15:00, Oct 08, 1990

Location of sample: Right Bank

Duration = 19.40Hrs
Time to Peak = 55.00Hrs
Background Conc.= 0.025ppb
Peak Conc. = 1.055ppb

Discharge = 108.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.850Kg
Recovery Ratio= 0.963

POSITION TIME (Hrs)

Leading edge: 50.78
Cp/2 : 52.58
Peak : 55.00
Centroid : 58.20
Mean : 56.39
Cp/2 : 61.88
Est. End Pt.: 70.19

Half-Duration= 9.30Hrs
Variance = 10.50
Skewness = 0.91
Kurtosis = 0.16
Alpha = 8.24
Beta = 0.00347

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
50.78	0.00	0.000
51.00	0.22	0.048
51.50	0.72	0.159
52.00	1.22	0.323
52.33	1.55	0.425
52.67	1.88	0.565
53.00	2.22	0.677
53.33	2.55	0.809
53.67	2.88	0.895
54.00	3.22	0.944
54.33	3.55	1.013
54.67	3.88	0.985
55.00	4.22	1.055
55.33	4.55	0.952
55.67	4.88	0.970
56.00	5.22	1.026
57.00	6.22	0.930
57.67	6.88	0.849
58.33	7.55	0.789
59.13	8.35	0.729
59.67	8.88	0.702
60.25	9.47	0.642
61.25	10.47	0.587
62.58	11.80	0.461
63.58	12.80	0.358
64.50	13.72	0.309
65.50	14.72	0.254
70.19	19.40	0.000

```
Sample Site: Elk Point Bridge on HWY 41, 574.0 km
Injection @ Shandro Bridge (638.8 km) @ 15:00, Oct 08, 1990

Location of sample: Section Average

Duration         =   18.56Hrs        Discharge     = 108.00CMS
Time to Peak     =   55.00Hrs        Dye Injected  =    3.998Kg
Background Conc.=    0.025ppb        Dye Recovered =    3.920Kg
Peak Conc.       =   1.121ppb        Recovery Ratio=    0.980

POSITION    TIME (Hrs)

Leading edge:   50.52           Half-Duration=    8.78Hrs
Cp/2        :   52.52           Variance     =   10.16
Peak        :   55.00           Skewness     =    0.94
Centroid    :   57.85           Kurtosis     =    0.28
Mean        :   56.25           Alpha        =    7.58
Cp/2        :   61.30           Beta         =    0.00336
Est. End Pt.:   69.08

TIME FROM    TIME FROM    CONCENTRATION
INJECTION   LEADING EDGE
  (Hrs)        (Hrs)          (ppb)
  50.52         0.00          0.000
  51.00         0.48          0.098
  51.50         0.98          0.200
  52.00         1.48          0.365
  52.33         1.81          0.491
  52.67         2.15          0.614
  53.00         2.48          0.742
  53.33         2.81          0.841
  53.67         3.15          0.939
  54.00         3.48          1.033
  54.33         3.81          1.059
  54.67         4.15          1.043
  55.00         4.48          1.121
  55.33         4.81          1.062
  55.67         5.15          1.053
  56.00         5.48          1.045
  57.00         6.48          0.964
  57.67         7.15          0.892
  58.33         7.81          0.852
  59.13         8.61          0.743
  59.67         9.15          0.700
  60.25         9.73          0.653
  61.25        10.73          0.565
  62.58        12.06          0.438
  63.58        13.06          0.356
  64.50        13.98          0.295
  65.50        14.98          0.232
  69.08        18.56          0.000
```

```
Sample Site: Heinsburg near HWY 893 Bridge, 540.5 km
Injection @ Shandro Bridge (683.8 km) @ 15:00. Oct 8, 1990

Location of sample: Left Bank

Duration          =   26.76Hrs        Discharge     = 124.00CMS
Time to Peak      =   77.00Hrs        Dye Injected  =    3.998Kg
Background Conc.=     0.022ppb        Dye Recovered =    3.761Kg
Peak Conc.        =   0.675ppb        Recovery Ratio=    0.941

POSITION    TIME (Hrs)

Leading edge:    68.46          Half-Duration=   11.96Hrs
Cp/2        :    71.35          Variance     =   18.31
Peak        :    77.00          Skewness     =    1.04
Centroid    :    78.54          Kurtosis     =    1.11
Mean        :    76.36          Alpha        =    7.82
Cp/2        :    83.32          Beta         =    0.00309
Est. End Pt.:    95.22

TIME FROM   TIME FROM   CONCENTRATION
INJECTION  LEADING EDGE
  (Hrs)       (Hrs)          (ppb)
  68.46        0.00          0.000
  69.00        0.54          0.052
  70.00        1.54          0.149
  70.50        2.04          0.219
  71.00        2.54          0.289
  71.50        3.04          0.358
  72.00        3.54          0.443
  72.50        4.04          0.478
  73.00        4.54          0.524
  73.50        5.04          0.573
  74.00        5.54          0.603
  74.50        6.04          0.627
  75.00        6.54          0.652
  75.50        7.04          0.624
  76.00        7.54          0.648
  77.00        8.54          0.675
  78.00        9.54          0.623
  79.00       10.54          0.569
  80.00       11.54          0.528
  81.00       12.54          0.475
  82.00       13.54          0.400
  84.00       15.54          0.305
  86.00       17.54          0.205
  88.00       19.54          0.133
  90.00       21.54          0.088
  92.00       23.54          0.061
  95.22       26.76          0.000
```

Sample Site: Heinsburg near HWY 893 Bridge, 540.5 km
Injection @ Shandro Bridge (683.8 km) @ 15:00. Oct 8, 1990

Location of sample: Centerline

Duration = 26.88Hrs
Time to Peak = 75.00Hrs
Background Conc.= 0.022ppb
Peak Conc. = 0.676ppb

Discharge = 124.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.746Kg
Recovery Ratio= 0.937

POSITION	TIME (Hrs)
Leading edge:	67.70
Cp/2 :	70.61
Peak :	75.00
Centroid :	77.77
Mean :	75.78
Cp/2 :	82.36
Est. End Pt.:	94.58

Half-Duration= 11.75Hrs
Variance = 17.53
Skewness = 1.11
Kurtosis = 1.40
Alpha = 7.87
Beta = 0.00312

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
67.70	0.00	0.000
68.00	0.30	0.024
69.00	1.30	0.104
70.00	2.30	0.239
70.50	2.80	0.319
71.00	3.30	0.403
71.50	3.80	0.478
72.00	4.30	0.503
72.50	4.80	0.564
73.00	5.30	0.603
73.50	5.80	0.633
74.00	6.30	0.658
74.50	6.80	0.670
75.00	7.30	0.676
75.50	7.80	0.648
76.00	8.30	0.660
77.00	9.30	0.621
78.00	10.30	0.587
79.00	11.30	0.528
80.00	12.30	0.473
81.00	13.30	0.421
82.00	14.30	0.356
84.00	16.30	0.256
86.00	18.30	0.171
88.00	20.30	0.119
90.00	22.30	0.077
92.00	24.30	0.048
94.58	26.88	0.000

```
Sample Site: Heinsburg near HWY 893 Bridge, 540.5 km
Injection @ Shandro Bridge (683.8 km) @ 15:00. Oct 8, 1990

Location of sample: Right Bank

Duration          =   26.91Hrs        Discharge     = 124.00CMS
Time to Peak      =   74.50Hrs        Dye Injected  =   3.998Kg
Background Conc.=     0.022ppb        Dye Recovered =   3.811Kg
Peak Conc.        =   0.664ppb        Recovery Ratio=   0.953

POSITION    TIME (Hrs)

Leading edge:   68.05           Half-Duration=   12.13Hrs
Cp/2        :   70.84           Variance     =   18.41
Peak        :   74.50           Skewness     =    1.11
Centroid    :   78.10           Kurtosis     =    1.28
Mean        :   75.98           Alpha        =    7.99
Cp/2        :   82.96           Beta         =    0.00332
Est. End Pt.:   94.96

TIME FROM   TIME FROM   CONCENTRATION
INJECTION  LEADING EDGE
  (Hrs)       (Hrs)         (ppb)
  68.05        0.00         0.000
  69.00        0.95         0.109
  70.00        1.95         0.224
  70.50        2.45         0.299
  71.00        2.95         0.348
  71.50        3.45         0.463
  72.00        3.95         0.473
  72.50        4.45         0.545
  73.00        4.95         0.603
  73.50        5.45         0.646
  74.00        5.95         0.621
  74.50        6.45         0.664
  75.00        6.95         0.658
  75.50        7.45         0.648
  76.00        7.95         0.648
  77.00        8.95         0.633
  78.00        9.95         0.593
  79.00       10.95         0.534
  80.00       11.95         0.480
  81.00       12.95         0.441
  82.00       13.95         0.371
  84.00       15.95         0.290
  86.00       17.95         0.195
  88.00       19.95         0.134
  90.00       21.95         0.086
  92.00       23.95         0.059
  94.96       26.91         0.000
```

Sample Site: Heinsburg near HWY 893 Bridge, 540.5 km
Injection @ Shandro Bridge (683.8 km) @ 15:00. Oct 8, 1990

Location of sample: Section Average

Duration = 27.32Hrs
Time to Peak = 75.00Hrs
Background Conc.= 0.022ppb
Peak Conc. = 0.662ppb

Discharge = 124.00CMS
Dye Injected = 3.998Kg
Dye Recovered = 3.780Kg
Recovery Ratio= 0.945

POSITION	TIME (Hrs)
Leading edge:	67.62
Cp/2 :	70.88
Peak :	75.00
Centroid :	78.12
Mean :	76.02
Cp/2 :	82.98
Est. End Pt.:	94.94

Half-Duration= 12.10Hrs
Variance = 18.20
Skewness = 1.08
Kurtosis = 1.24
Alpha = 8.04
Beta = 0.00323

TIME FROM INJECTION (Hrs)	TIME FROM LEADING EDGE (Hrs)	CONCENTRATION (ppb)
67.62	0.00	0.000
68.00	0.38	0.024
69.00	1.38	0.088
70.00	2.38	0.204
70.50	2.88	0.279
71.00	3.38	0.347
71.50	3.88	0.433
72.00	4.38	0.473
72.50	4.88	0.529
73.00	5.38	0.577
73.50	5.88	0.617
74.00	6.38	0.627
74.50	6.88	0.654
75.00	7.38	0.662
75.50	7.88	0.640
76.00	8.38	0.652
77.00	9.38	0.643
78.00	10.38	0.601
79.00	11.38	0.543
80.00	12.38	0.494
81.00	13.38	0.446
82.00	14.38	0.376
84.00	16.38	0.284
86.00	18.38	0.191
88.00	20.38	0.128
90.00	22.38	0.083
92.00	24.38	0.056
94.94	27.32	0.000

```
Sample Site: Meridian Bridge on HWY 34, 494.2 km
Injection @ Shandro Bridge (683.8 km) @ 15:00, Oct 8, 1990

Location of sample: Left Bank

Duration          =   29.72Hrs        Discharge      = 137.00CMS
Time to Peak      =  102.50Hrs        Dye Injected   =   3.998Kg
Background Conc.=    0.025ppb         Dye Recovered =    3.787Kg
Peak Conc.        =   0.537ppb        Recovery Ratio=    0.947

POSITION    TIME (Hrs)

Leading edge:    91.41          Half-Duration=    13.81Hrs
Cp/2        :    97.84          Variance     =    24.63
Peak        :   102.50          Skewness     =     0.64
Centroid    :   105.39          Kurtosis     =    -0.15
Mean        :   103.86          Alpha        =     7.74
Cp/2        :   111.65          Beta         =     0.00234
Est. End Pt.:   121.13

TIME FROM    TIME FROM    CONCENTRATION
INJECTION   LEADING EDGE
  (Hrs)         (Hrs)          (ppb)
  91.41         0.00          0.000
  95.00         3.59          0.093
  95.50         4.09          0.106
  96.00         4.59          0.146
  96.50         5.09          0.161
  97.00         5.59          0.209
  97.50         6.09          0.250
  98.00         6.59          0.277
  98.50         7.09          0.317
  99.00         7.59          0.366
  99.50         8.09          0.400
 100.00         8.59          0.423
 100.50         9.09          0.452
 101.00         9.59          0.453
 101.50        10.09          0.516
 102.00        10.59          0.509
 102.50        11.09          0.537
 103.00        11.59          0.521
 103.50        12.09          0.526
 104.00        12.59          0.533
 104.50        13.09          0.498
 105.00        13.59          0.506
 106.00        14.59          0.457
 107.00        15.59          0.422
 108.00        16.59          0.387
 109.00        17.59          0.356
 110.00        18.59          0.334
 111.00        19.59          0.297
 112.00        20.59          0.253
 113.00        21.59          0.232
 114.00        22.59          0.192
 115.00        23.59          0.162
 116.00        24.59          0.137
 117.00        25.59          0.109
 121.13        29.72          0.000
```

```
Sample Site: Meridian Bridge on HWY 34, 494.2 km
Injection @ Shandro Bridge (683.8 km) @ 15:00, Oct 8, 1990

Location of sample: Centerline

Duration          =   26.75Hrs        Discharge     = 137.00CMS
Time to Peak      =  102.00Hrs        Dye Injected  =    3.998Kg
Background Conc.=    0.025ppb         Dye Recovered =    3.771Kg
Peak Conc.        =   0.604ppb        Recovery Ratio=    0.943

POSITION     TIME (Hrs)

Leading edge:    93.20           Half-Duration=    11.94Hrs
Cp/2         :   96.50           Variance     =    21.61
Peak         :  102.00           Skewness     =     0.79
Centroid     :  103.80           Kurtosis     =     0.40
Mean         :  102.49           Alpha        =     6.60
Cp/2         :  108.44           Beta         =     0.00208
Est. End Pt.:   119.95

TIME FROM    TIME FROM    CONCENTRATION
INJECTION   LEADING EDGE
  (Hrs)        (Hrs)          (ppb)
  93.20         0.00          0.000
  94.50         1.30          0.120
  95.00         1.80          0.166
  95.50         2.30          0.200
  96.00         2.80          0.253
  96.50         3.30          0.302
  97.00         3.80          0.337
  97.50         4.30          0.398
  98.00         4.80          0.412
  98.50         5.30          0.466
  99.00         5.80          0.502
  99.50         6.30          0.529
 100.00         6.80          0.546
 100.50         7.30          0.567
 101.00         7.80          0.600
 101.50         8.30          0.591
 102.00         8.80          0.604
 102.50         9.30          0.571
 103.00         9.80          0.561
 103.50        10.30          0.526
 104.00        10.80          0.519
 104.50        11.30          0.498
 105.00        11.80          0.466
 106.00        12.80          0.416
 107.00        13.80          0.378
 108.00        14.80          0.327
 109.00        15.80          0.270
 110.00        16.80          0.253
 111.00        17.80          0.211
 112.00        18.80          0.186
 113.00        19.80          0.150
 114.00        20.80          0.126
 115.00        21.80          0.101
 116.00        22.80          0.075
 117.00        23.80          0.061
 119.95        26.75          0.000
```

```
Sample Site: Meridian Bridge on HWY 34, 494.2 km
Injection @ Shandro Bridge (683.8 km) @ 15:00, Oct 8, 1990

Location of sample: Right Bank

Duration          =   28.38Hrs        Discharge      = 137.00CMS
Time to Peak      =  101.00Hrs        Dye Injected   =   3.998Kg
Background Conc.=    0.025ppb        Dye Recovered =   3.920Kg
Peak Conc.        =    0.635ppb        Recovery Ratio=   0.980

POSITION    TIME (Hrs)

Leading edge:   92.26          Half-Duration=   11.58Hrs
Cp/2        :   96.59          Variance     =   20.68
Peak        :  101.00          Skewness     =    0.82
Centroid    :  103.62          Kurtosis     =    0.49
Mean        :  102.48          Alpha        =    6.49
Cp/2        :  108.17          Beta         =    0.00203
Est. End Pt.:  120.64

TIME FROM   TIME FROM   CONCENTRATION
INJECTION  LEADING EDGE
  (Hrs)        (Hrs)        (ppb)
  92.26        0.00        0.000
  95.00        2.74        0.180
  95.50        3.24        0.213
  96.00        3.74        0.267
  96.50        4.24        0.309
  97.00        4.74        0.358
  97.50        5.24        0.418
  98.00        5.74        0.439
  98.50        6.24        0.479
  99.00        6.74        0.516
  99.50        7.24        0.536
 100.00        7.74        0.560
 100.50        8.24        0.574
 101.00        8.74        0.635
 101.50        9.24        0.631
 102.00        9.74        0.618
 102.50       10.24        0.584
 103.00       10.74        0.574
 103.50       11.24        0.547
 104.00       11.74        0.554
 104.50       12.24        0.511
 105.00       12.74        0.499
 106.00       13.74        0.437
 107.00       14.74        0.371
 108.00       15.74        0.327
 109.00       16.74        0.270
 110.00       17.74        0.247
 111.00       18.74        0.217
 112.00       19.74        0.186
 113.00       20.74        0.143
 114.00       21.74        0.112
 115.00       22.74        0.094
 116.00       23.74        0.075
 117.00       24.74        0.061
 120.64       28.38        0.000
```

```
Sample Site: Meridian Bridge on HWY 34, 494.2 km
Injection @ Shandro Bridge (683.8 km) @ 15:00, Oct 8, 1990

Location of sample: Section Average

Duration          =   28.44Hrs         Discharge     = 137.00CMS
Time to Peak      =  101.50Hrs         Dye Injected  =   3.998Kg
Background Conc.=     0.025ppb         Dye Recovered =   3.834Kg
Peak Conc.        =   0.579ppb         Recovery Ratio=   0.959

POSITION    TIME (Hrs)

Leading edge:   92.20            Half-Duration=   12.58Hrs
Cp/2        :   96.87            Variance     =   22.95
Peak        :  101.50            Skewness     =    0.74
Centroid    :  104.24            Kurtosis     =    0.22
Mean        :  102.86            Alpha        =    6.90
Cp/2        :  109.45            Beta         =    0.00223
Est. End Pt.:  120.63

TIME FROM   TIME FROM   CONCENTRATION
INJECTION  LEADING EDGE
  (Hrs)        (Hrs)         (ppb)
  92.20         0.00         0.000
  94.50         2.30         0.120
  95.00         2.80         0.146
  95.50         3.30         0.173
  96.00         3.80         0.222
  96.50         4.30         0.257
  97.00         4.80         0.301
  97.50         5.30         0.355
  98.00         5.80         0.376
  98.50         6.30         0.421
  99.00         6.80         0.461
  99.50         7.30         0.489
 100.00         7.80         0.510
 100.50         8.30         0.531
 101.00         8.80         0.563
 101.50         9.30         0.579
 102.00         9.80         0.577
 102.50        10.30         0.564
 103.00        10.80         0.552
 103.50        11.30         0.533
 104.00        11.80         0.535
 104.50        12.30         0.502
 105.00        12.80         0.490
 106.00        13.80         0.437
 107.00        14.80         0.391
 108.00        15.80         0.347
 109.00        16.80         0.299
 110.00        17.80         0.278
 111.00        18.80         0.242
 112.00        19.80         0.209
 113.00        20.80         0.175
 114.00        21.80         0.143
 115.00        22.80         0.119
 116.00        23.80         0.096
 117.00        24.80         0.077
 120.63        28.44         0.000
```